

Author: Armsby, Henry Prentiss

Title: Animal nutrition

Place of Publication:

Copyright Date: 1922?

Master Negative Storage Number: MNS# PSt SNP aAg052.4

<383318> * *OCLC* Form:mono 2 Input:LCH Edit:FMD
 008 ENT: 980120 TYP: s DT1: 1922 DT2: LAN: eng
 035 (OCoLC)38225206
 037 PSt SNPaAg052.4 \$bPreservation Office, The Pennsylvania State University, Pattee Library, University Park, PA 16802-1805
 090 00 SF95 \$b.A75 1922 \$cpn*10326985
 090 20 Microfilm D344 reel 52.4 \$cmc+(service copy, print master, archival master)
 100 1 Armsby, Henry Prentiss \$d1853-1921.
 245 10 Animal nutrition \$binvestigations at the Institute of Animal Nutrition of the Pennsylvania State College with the co-operation of the Bureau of Animal Industry of the United States Department of Agriculture : collected papers, 1912-1922 \$cby Henry Prentiss Armsby and J. August Fries
 260 [S.l. \$bs.n.] \$c[1922?]
 300 1 v. (various pagings) \$bill. \$c23 cm.
 500 A collection of reprints and government documents
 504 Includes bibliographical references.
 533 Microfilm \$bUniversity Park, Pa. : \$cPennsylvania State University \$d1997. \$e1 microfilm reel ; 35 mm. \$f(USAIN state and local literature preservation project. Pennsylvania) \$f(Pennsylvania agricultural literature on microfilm).
 590 Archival master stored at National Agricultural Library, Beltsville, MD : print master stored at remote facility.
 590 This item is temporarily out of the library during the filming process. If you wish to be notified when it returns, please fill out a Personal Reserve slip. The slips are available in the Rare Books Room, in the Microforms Room, and at the Circulation desk.
 650 0 Animal nutrition
 700 1 Fries, J. August \$d1853-1921.
 700 1 Armsby, Henry Prentiss \$d1853-1921. \$tCollected papers, 1912-1922.
 710 2 Pennsylvania State College. \$bInstitute of Animal Nutrition.
 710 1 United States. \$bBureau of Animal Industry.
 830 0 USAIN state and local literature preservation project. \$pPennsylvania.
 830 0 Pennsylvania agricultural literature on microfilm.

ANIMAL NUTRITION

Investigations at the Institute of Animal
Nutrition of the Pennsylvania State Col-
lege with the co-operation of The Bureau
of Animal Industry of the United States
Department of Agriculture

COLLECTED PAPERS

1912-1922

By

HENRY PRENTISS ARMSBY

and

J. AUGUST FRIES

INDEX

1. The Maintenance Rations of Farm Animals.
2. Adiabatic Device for Bomb Calorimeter.
3. The Influence of Standing or Lying Upon the Metabolism of Cattle.
4. The Influence of Standing or Lying Upon the Metabolism of Cattle.
5. The Combustible Gases Excreted by Cattle.
6. A Comparison of the Observed and Computed Heat Production of Cattle.
7. Food as Body Fuel
8. A Study in Drying Urine for Chemical Analysis.
9. Net Energy Values of Feeding Stuffs for Cattle.
10. The Determination of Ammonia Nitrogen in Steer's Urine.
11. Net Energy Values for Ruminants.
12. Computation of Dairy Rations.
13. Energy Values of Red Clover Hay and Maize Meal.
14. The Use of Energy Values in the Computation of Rations for Farm Animals.
15. Weak Places in the Methods Used in Animal Nutrition Investigations
16. Energy Values of Hominy Feed and Maize Meal for Cattle.
17. The Influence of the Degree of Fatness of Cattle Upon Their Utilization of Feed.
18. Influence of the Degree of Fatness of Cattle Upon Their Utilization of Feed.
19. The Basal Katabolism of Cattle and Other Species.
20. Basal Katabolism of Cattle and Other Species.
21. Net Energy Values of Alfalfa Hay and of Starch.
22. Net Energy Values and Starch Values.
23. A National Institute of Nutrition.
24. The Modern Science of Food Values
25. The Carbon Dioxide: Heat Ratio in Cattle.
26. Observations on the Body Temperature of Dry Cows.
27. Observations on the Body Temperature of Dry Cows.
28. The Influence of Potassium Permanganate on Kjeldahl Nitrogen Determinations.
29. The Respiratory Quotient and its Uncertainty.
30. Some Fundamentals of Stable Ventilation.
31. Bulletin of the National Research Council.
32. Heat Values and Food Values.
33. The Promotion of Agricultural Science.
34. Research as a Career.

Issued February 15, 1912.

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF ANIMAL INDUSTRY.—BULLETIN 143.

A. D. MELVIN, CHIEF OF BUREAU.

THE MAINTENANCE RATIONS OF
FARM ANIMALS.

BY

HENRY PRENTISS ARMSBY, PH. D., LL. D.,

*Director of the Institute of Animal Nutrition of The Pennsylvania
State College; Expert in Animal Nutrition,
Bureau of Animal Industry.*



WASHINGTON:
GOVERNMENT PRINTING OFFICE.

1912.

THE BUREAU OF ANIMAL INDUSTRY.

Chief: A. D. MELVIN.

Assistant Chief: A. M. FARRINGTON.

Chief Clerk: CHARLES C. CARROLL.

Animal Husbandry Division: GEORGE M. ROMMEL, chief.

Biochemic Division: M. DORSET, chief.

Dairy Division: B. H. RAWL, chief.

Inspection Division: RICE P. STEDDOM, chief; MORRIS WOODEN, R. A. RAMSAY,
and ALBERT E. BEHNKE, associate chiefs.

Pathological Division: JOHN R. MOHLER, chief.

Quarantine Division: RICHARD W. HICKMAN, chief.

Zoological Division: B. H. RANSOM, chief.

Experiment Station: E. C. SCHROEDER, superintendent.

Editor: JAMES M. PICKENS.

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,

BUREAU OF ANIMAL INDUSTRY,

Washington, D. C., August 12, 1911.

SIR: I have the honor to transmit herewith, and to recommend for publication in the bulletin series of this bureau, a manuscript entitled "The Maintenance Rations of Farm Animals," by Dr. Henry Prentiss Armsby, who has charge of the cooperative work in animal nutrition between this bureau and the Institute of Animal Nutrition of The Pennsylvania State College. The paper is based not only on Dr. Armsby's own work, but on that of other investigators as well, and is believed to cover the subject thoroughly.

Respectfully,

A. D. MELVIN,
Chief of Bureau.

Hon. JAMES WILSON,
Secretary of Agriculture.

CONTENTS.

	Page.
Introduction.....	7
The fasting katabolism.....	8
Purpose of the fasting katabolism.....	9
The material katabolized.....	10
Ash.....	10
Fat.....	10
Carbohydrates.....	10
Protein.....	11
Ratio of protein to total katabolism.....	11
Influence of body fat.....	12
Influence of surplus protein.....	13
Relative constancy of energy katabolism.....	13
The energy requirement for maintenance.....	16
Replacement of nutrients.....	16
Feed fat and body fat.....	16
Carbohydrates and body fat.....	17
Carbohydrates and feed fat.....	17
Feed protein and body fat.....	17
Fat or carbohydrates and protein.....	18
Availability of energy.....	19
Availability for cattle.....	20
Availability for the horse—Zuntz and Hagemann's results.....	22
Digestive work for crude fiber.....	23
Work of mastication.....	23
Computation of available energy.....	24
Availability for the horse—Wolff's results.....	25
Availability for carnivora.....	26
Causes of increased metabolism.....	28
Mechanical work.....	29
Secretion.....	29
Fermentation.....	29
Digestive cleavages.....	30
Intermediary metabolism.....	31
Excretion.....	32
The maintenance ration.....	33
Relation of maintenance requirement to live weight.....	36
Computation of relative body surface.....	38
The maintenance rations of farm animals.....	39
Cattle.....	39
Sheep.....	48
Swine.....	51
The horse.....	55
Zuntz and Hagemann's investigations.....	55
Wolff's investigations.....	57
Müntz's experiments.....	62
Grandeau and Le Clerc's results.....	62
True maintenance and live-weight maintenance.....	6

	Page.
Factors affecting the energy requirement.....	64
Muscular activity.....	65
Minor muscular motions.....	65
Lying and standing.....	66
Individuality.....	66
Condition.....	67
Age.....	68
External temperature.....	69
Regulation of body temperature.....	69
Critical temperature.....	71
Feed consumption a source of heat.....	71
Isodynamic replacement.....	72
Relation of maintenance ration to critical temperature.....	72
Feed consumption lowers the critical temperature.....	73
Critical temperature for farm animals.....	73
The protein requirement for maintenance.....	74
Protein katabolized during fasting.....	74
Influence of previous feed.....	74
Fasting katabolism variable.....	74
The minimum of protein.....	75
Influence of nonnitrogenous materials.....	76
Relation to fasting katabolism.....	76
Effect of surplus of protein.....	78
Increases protein katabolism.....	78
Utilization of protein limited.....	80
Protein as a source of energy.....	81
Storage of protein.....	82
Fluctuations in body protein.....	83
Relation to energy supply.....	84
Value of nonprotein.....	88
Minimum of protein for farm animals.....	89
Cattle.....	89
Sheep.....	94
Swine.....	96
The horse.....	97
The optimum of protein.....	97
Relative values of proteins.....	99
Differences in constitution of proteins.....	99
Absence of certain constituents.....	100
Proportions of constituents.....	101
Experimental methods.....	102
Michaud's investigations.....	102
Zisterer's experiments.....	104
Results are qualitative.....	105
Thomas's experiments.....	106
Significance of results.....	108

ILLUSTRATION.

FIGURE 1.—Availability of metabolizable energy of hay.....

Page.
35

THE MAINTENANCE RATIIONS OF FARM ANIMALS.

INTRODUCTION.

Feed is supplied to farm animals in order that they may either yield products useful to man as materials for human food and clothing or serve him by the performance of mechanical work. But as a factory must first be supplied with enough power to keep in motion the shafting, belting, and other machinery before any product can be turned out, so the animal mechanism must be provided with sufficient feed to maintain the processes essential to life before any continued production is possible. The amount of feed required for this purpose is called the maintenance ration of the particular animal. It is the quantity of feed necessary simply to support the animal when doing no work and yielding no material product. If an animal receiving exactly a maintenance ration were subjected to a so-called balance experiment, there would be found an exact equality between income and outgo of ash, nitrogen, carbon, hydrogen, and energy, showing that the body was neither gaining nor losing protein, fat, carbohydrates, or ash.

The word "maintenance" is sometimes used popularly in another sense to signify the total amount of feed required, for example, by a horse in order to perform his daily work or by a calf in order to make a normal growth. It is important to grasp the idea that, in its technical sense, the maintenance requirement means the minimum required simply to sustain life. The feed of the horse or calf would, from this point of view, be regarded as consisting of two portions; one of these is the maintenance ration, which if fed by itself would just support the horse at rest or the calf without growth, and the other the productive portion of the ration by means of which work is done or growth made. To recur to the illustration of the factory, the maintenance ration keeps the empty machinery running, while the additional feed furnishes the power necessary to turn out the product.

It might seem at first thought that not much importance attaches to a study of the maintenance ration. The animal kept on such a ration yields no direct economic return and hence simple maintenance feeding should be avoided, so far as practicable, and when

it appears desirable to practice it the observation of the skilled stockman, especially if supplemented by occasional weighings, will usually suffice to determine whether or not the end is being attained. Nevertheless, the subject has significance for practice as well as for science. A very considerable fraction of the feed actually consumed by farm animals—on the average probably fully one-half—is applied simply to maintenance. But if half of the farmer's feed bill is expended for maintenance, it is clearly important for him to know something of the laws of maintenance—how its requirements vary as between different animals, how they are affected by the conditions under which animals are kept, how different feeding stuffs compare in value, etc.—as well as to understand the principles governing the production of meat, milk, or work from the other half of his feed.

Physiologically, too, the maintenance requirement represents the demand of the basal life processes. The prime necessity of the organism is to maintain itself. It must live before it can grow or propagate its kind, and in the phenomena of maintenance the fundamental processes of nutrition may be studied uncomplicated by the demands of growth, fattening, or reproduction.

THE FASTING KATABOLISM.¹

Unlike the operations of a factory, which cease when the power is shut off, the activities of the animal do not stop when food is withdrawn, but continue for a variable length of time at the expense of the materials of the body. It is as if the materials of the factory itself were being cut up and used for fuel under the boilers. Men have fasted voluntarily for 30 days or more without obvious permanent ill effects, and there are records of dogs having survived fasting periods of from 90 to 100 or more days. In the fasting animal at rest the vital activities are reduced, as it were, to their simplest terms, practically only those functions being active which are essential to continued life. The following approximate estimate by Zuntz of the factors of the katabolism of a fasting man may serve to give a general idea of their nature and relative importance. The figures show the oxygen consumption per minute of the various tissues and its percentage distribution:

¹ For references to the literature of the fasting katabolism compare:
Magnus Levy. Von Noorden's Pathologie des Stoffwechsels, 2d ed., I, 222-225 and 310-315.
Tigerstedt. Nagel's Handbuch der Physiologie des Menschen, I, 375-391.
Lusk. The Science of Nutrition. 2d ed., 54-85.
Benedict. Metabolism in Inanition. Carnegie Institution of Washington, Publication No. 77, II, 361-364.
Armsby. Principles of Animal Nutrition, 3d ed., 80-92 and 340-347.

Consumption of oxygen in fasting man weighing 70 kilograms—Zuntz.

	Cubic centimeters per minute.	Percentage.
Circulation and respiration.....	30.0	12.45
Voluntary muscles.....	112.0	46.49
Glands and other organs:		
Liver.....	45.0	18.68
Small intestine.....	25.1	10.42
Kidneys.....	10.5	4.36
Pancreas.....	9.3	3.86
Large intestine.....	7.0	2.91
Salivary glands.....	2.0	.83
	98.9	41.06
Total.....	240.9	100.00

According to the foregoing table nearly 60 per cent of the metabolism of a fasting man is due to the work of the muscles, including that of respiration and circulation as well as the limited activity of the voluntary muscles, while somewhat over 40 per cent is due to the internal organs. No equally complete data are available for farm animals, but the supposition seems justified that their metabolism in its main features is not greatly unlike that of man. It may be noted that Zuntz and Hagemann found the energy expended in respiration and circulation by the horse in a state of rest to be, respectively, 4.7 and 5.01 per cent of the total metabolism. The sum of these—9.71 per cent—is approximately comparable with the corresponding figure for man.

PURPOSE OF THE FASTING KATABOLISM.

The animal body is primarily a transformer of energy. From the biochemical standpoint the essential phenomenon of physical life is the transformation of chemical into kinetic energy which accompanies the breaking down of more or less complex molecules into simpler ones, and all vital activities are essentially manifestations of energy. In the fasting state this energy is derived from the store of chemical energy contained in the materials of the body itself. The very act of living, in the foregoing view of it, is synonymous with the expenditure by the organism of its stored-up capital of energy. The prime and dominating purpose of the fasting katabolism, therefore, is to supply energy for the life actions.

But since the necessary activities of the fasting organism are carried on by means of energy derived from the katabolism of materials contained in the tissues, the body's store of matter and of energy is being constantly depleted. To prevent or replace this loss will require a corresponding supply of available material and energy in the feed. A knowledge of the kind and quantity of material katabolized during fasting and of the amount of energy liberated, therefore, is obviously the first step toward ascertaining the supply necessary in the feed.

THE MATERIAL KATABOLIZED.

Ash.—The fasting organism suffers a continual loss of the so-called ash ingredients of its tissues, including both the sulphur and phosphorus of its proteins and the more distinctly "mineral" elements, such as sodium, potassium, calcium, magnesium, chlorine, etc. These elements are just as essential to the existence of the animal as are the carbon, nitrogen, hydrogen, and oxygen of the so-called "organic" compounds.

The study of this branch of the subject, however, has hardly progressed far enough as yet to permit a definite formulation of the ash requirements of domestic animals. The present paper, therefore, will be confined to a discussion of the maintenance requirements in the more limited and customary sense, including only those substances whose function it is wholly or in part to serve as sources of energy.

Fat.—It is a familiar conception that fat formation is the body's method of disposing of surplus feed, and that the body fat is a store of reserve fuel material. The converse of this fact is equally familiar. The fasting or insufficiently fed animal loses fat and may reach a stage of extreme emaciation before the active tissues fail to perform their duties. Obviously, the fasting animal lives very largely upon its reserve fat. These conclusions from common observation have been fully confirmed by comparative analyses of the carcasses of well-fed and of fasted animals as well as by the results of balance experiments in which the exact nature of the outgo from the body has been determined.

Carbohydrates.—In addition to fat, the body stores up more or less nonnitrogenous matter in the form of glycogen in the liver and muscles. During the first few days of fasting this store of carbohydrates is also drawn upon, as is indicated by the fact that the respiratory quotient tends to approach unity, while later the amount katabolized becomes very small. This is well illustrated by Benedict's¹ experiments upon fasting men. The average results of a number of experiments in which men fasted for from two to seven consecutive days were as follows:

Glycogen katabolized by fasting men—Benedict.

Day.	Number of subjects.	Glycogen katabolized.	
		Total.	Per kilogram of body weight.
		Grams.	Grams.
First day.....	14	110.0	1.69
Second day.....	13	40.3	.62
Third day.....	6	21.8	.36
Fourth day.....	5	23.3	.40
Fifth day.....	1	8.2	.14
Sixth day.....	1	21.7	.38
Seventh day.....	1	18.7	.33

¹ The Influence of Inanition on Metabolism. Carnegie Institution of Washington, D. C., 1907, p. 464.

² Another subject showed a slight gain of glycogen.

Protein.—Balance experiments, however, while confirming the conclusion that the loss of tissue in fasting usually consists chiefly of fat together with some carbohydrates, show that there is also a continual breaking down of body protein and a corresponding excretion of urinary nitrogen. While the energy supply of the fasting animal is chiefly derived from the breaking down of nonnitrogenous material, the functional activity of the tissues necessarily involves the katabolism of a certain amount of protein.

RATIO OF PROTEIN TO TOTAL KATABOLISM.

Qualitatively, then, the katabolism of the fasting animal is substantially a katabolism of fat and of protein, and it becomes of interest to consider the quantitative relations between the two. Such a comparison is best made on the basis of the amounts of energy liberated in the body in the katabolism of protein and of fat respectively. This aspect of the subject has been treated especially in an article by E. Voit² in which the results of a considerable number of fasting experiments are compiled and discussed. While some of Voit's computations are based on estimates, they are sufficiently accurate to outline definitely the main features of the fasting katabolism. Including only experiments on animals well nourished at the beginning, he obtained the following averages for the percentage of the total energy liberated which was supplied by the katabolism of protein in the case of a number of different species. The results of the first day or two of fasting are not included in the averages.

Proportion of energy derived from protein in fasting—E. Voit.

Kind of animal.	Live weight.	Protein katabolism in per cent of total katabolism.
		Per cent.
Swine.....	Kilos. 115.0	7.3
Man.....	63.7	15.6
	28.6	13.2
Dog.....	18.7	10.7
	7.2	13.5
Rabbit.....	2.7	16.5
Guinea pig.....	.6	10.8
Goose.....	3.3	7.4
Hen.....	2.1	10.0

While both the total and protein katabolism naturally showed a wide range as to absolute amount, whether per head or per unit of live weight, the ratio of protein to total katabolism proved notably uniform with only two exceptions. The experiments upon dogs, 27 in number, included in the foregoing table furnished the basis for the following comparison, showing that in 74 per cent of the cases the ratio ranged from 10 to 17 per cent.

² Zeitschrift für Biologie, vol. 41, p. 167.

Protein katabolism of dog in per cent of total katabolism.

	Number of cases.	
	Absolute.	Per cent.
Less than 10 per cent.....	4	14.8
10 to 14 per cent.....	15	55.6
14 to 17 per cent.....	5	18.5
More than 17 per cent.....	3	11.1
	27	100.0

It may be accepted as established, then, that in what may be spoken of as the normal fasting animal, in which the influence of the previous feeding has disappeared and in which, on the other hand, the fat reserve has not been exhausted, the protein katabolism constitutes a fairly small percentage of the total katabolism, both being expressed in terms of energy.

INFLUENCE OF BODY FAT.

It is clear, however, from the foregoing figures that the ratio of protein to total katabolism may vary considerably. The most important factor in this variation has been found to be the relative amount of fat contained in the body. So long as fuel material in the form of body fat is readily available, the amount of protein katabolized remains small. Usually, however, the store of fat in the body is less than that of protein, while in fasting its exhaustion is relatively more rapid. There comes a time, therefore, when the supply of non-nitrogenous material to the tissues begins to flag. When this happens, the protein katabolism begins to increase—that is, when the supply of reserve fuel material runs low the organism begins to use the protein of its own tissues as a source of energy, and E. Voit¹ shows that this occurs whenever the ratio of fat to protein remaining in the body falls below a certain limit. If the animal was originally well fed, this rise in the protein katabolism occurs only shortly before death, from which fact it has received the name of the pre-mortal rise. In the case of very fat animals this point may never be reached, while, on the other hand, in a lean animal the protein katabolism may increase steadily from the very beginning of the fasting. The following three experiments upon a fat guinea pig, a moderately fat dog, and a lean rabbit, cited by Voit from Rubner's experiments, may serve to illustrate these three types of fasting katabolism:

¹ Loc. cit., p. 502.*Proportion of energy derived from protein—Rubner.*

Guinea pig.		Dog.		Rabbit.	
Day of fasting.	Protein katabolism in per cent of total katabolism.	Day of fasting.	Protein katabolism in per cent of total katabolism.	Day of fasting.	Protein katabolism in per cent of total katabolism.
	<i>Per cent.</i>		<i>Per cent.</i>		<i>Per cent.</i>
2.....	10.4	2-4.....	16.3	3.....	16.5
3.....	11.1	10-11.....	13.1	5-7.....	23.6
4.....	11.0	12.....	15.5	9-12.....	26.5
5.....	11.9	13.....	17.4	13-15.....	29.8
6.....	11.8	14.....	20.0	16.....	50.1
7.....	6.9			17-18.....	96.4
8.....	11.2				
9.....	10.9				

INFLUENCE OF SURPLUS PROTEIN.

On the other hand, as Pettenkofer and Voit long ago showed,¹ when an animal which has been previously receiving large amounts of protein is deprived of feed, the high protein katabolism which is observed during the first two or three days of fasting is accompanied by a relatively smaller katabolism of fat. Thus in an experiment with a dog, cited on a subsequent page (p. 74) to illustrate the initial fall of protein katabolism, respiration experiments were made on the second, fifth, and eighth days, with the following results:

Katabolism of fasting dog—Voit.

Day.	Urinary nitrogen.	Fat katabolized.	Protein katabolized in per cent of total katabolism.
	<i>Grams.</i>	<i>Grams.</i>	
Second day.....	11.6	86	26.2
Fifth day.....	5.7	103	12.7
Eighth day.....	4.7	99	11.1

Obviously we have here the reverse of what takes place in the later days of fasting, viz, a gradual substitution of fat for protein as the readily available supply of the latter in the body is reduced. Doubtless the effect would have been found to be still more marked on the first day of the fasting, when the protein katabolism was equivalent to 28.1 grams of nitrogen.

RELATIVE CONSTANCY OF ENERGY KATABOLISM.

The results which have just been considered regarding the nature of the material katabolized in fasting and the way in which fat,

¹ Zeitschrift für Biologie, vol. 7, p. 369.

carbohydrates, and protein mutually replace each other as fuel material as one or the other is most available fully substantiate the assertion made on page 9 that the controlling factor in the katabolism of the fasting body is the demand for energy. As there stated, the body is essentially a converter of energy, and protein occupies a peculiar position in nutrition simply so far as it is a part of the necessary mechanism for this conversion. These facts can hardly have failed to suggest that the demand for energy must be relatively constant in the same individual, and that such is in fact the case has been demonstrated by a large number of experiments.

For example, in the experiment by Voit upon a dog, just cited, the energy of the protein and fat katabolized on the three days, as computed from the data for the urinary nitrogen and for the fat katabolism, was as shown in the following table, from which it appears that the total energy katabolized, especially when computed per kilogram of live weight, was approximately the same on the different days.

Constancy of katabolism of fasting dog—Voit.

Day.	Live weight.	Energy from protein.	Energy from fat.	Total energy.	Total energy per kilogram live weight.
	Kilos.	Calories. ¹	Calories. ¹	Calories. ¹	Calories. ¹
Second day.....	32.87	289.3	816.9	1,106.2	33.66
Fifth day.....	31.67	142.2	978.5	1,120.7	35.38
Eighth day.....	30.54	117.2	942.4	1,059.6	34.70

¹ Throughout this bulletin the word "calorie" signifies the large, or kilogram, calorie, unless the contrary is specifically stated.

The same constancy is illustrated by Rubner's experiments on a rabbit, a dog, and a guinea pig, whose relative protein katabolism was tabulated on page 13. The latter is repeated in the following table, together with the heat production as measured directly or the carbon dioxid excreted, which may be assumed to be an approximate measure of the energy katabolized. As the table shows, notwithstanding very considerable variations in the relative amount of protein katabolized, the total energy liberated in the body was relatively very constant.

Constancy of katabolism of fasting animals—Rubner.

Day of fasting.	Guinea pig.		Dog.		Rabbit.	
	Protein katabolism in per cent of total katabolism.	Heat production per kilogram.	Protein katabolism in per cent of total katabolism.	Carbon dioxid per kilogram.	Protein katabolism in per cent of total katabolism.	Carbon dioxid per kilogram.
		Calories.		Grams.		Grams.
First.....		149.9		20.70		
Second.....	10.4	162.6		17.83		
Third.....	11.1	156.5	16.3		16.5	
Fourth.....	11.0	140.5		17.99		
Fifth.....	11.9	137.3				17.26
Sixth.....	11.8	150.6			23.6	15.90
Seventh.....	6.9	157.4				
Eighth.....	11.2	155.6				
Ninth.....	10.9	162.6				15.90
Tenth.....			13.1	18.70		15.65
Eleventh.....				17.86	26.5	
Twelfth.....			15.5	16.13		17.18
Thirteenth.....			17.4	17.06		15.81
Fourteenth.....			20.0	16.12	29.8	15.95
Fifteenth.....						15.90
Sixteenth.....					50.1	
Seventeenth.....					96.4	
Eighteenth.....						

Benedict¹ has obtained like results for the heat production of man as measured directly by means of the respiration calorimeter. For example, in an experiment² covering seven days the following quantities of energy were katabolized daily.

Constancy of katabolism of fasting man—Benedict.

Day of fasting.	Energy from protein.	Energy from fat.	Energy from glycogen.	Total energy.	Energy per kilogram body weight.	Protein katabolism in per cent of total katabolism.
	Calories.	Calories.	Calories.	Calories.	Calories.	Per cent.
First day.....	318	1,175	272	1,765	29.7	17.7
Second day.....	286	1,385	97	1,768	29.9	16.0
Third day.....	303	1,471	23	1,797	30.8	17.0
Fourth day.....	248	1,422	105	1,775	30.8	14.3
Fifth day.....	221	1,394	34	1,649	29.0	13.5
Sixth day.....	218	1,244	91	1,553	27.5	14.1
Seventh day.....	204	1,286	78	1,568	28.0	13.2

This constancy of the fasting katabolism evidently is in accord with the conception of it outlined on page 9 as the measure of the energy necessary to carry on the vital activities of the body. The functions of circulation, respiration, excretion, etc., must go on continually in a state of so-called rest, the muscular tonus must be maintained and divers minor muscular movements executed. In the aggregate all these result in the expenditure of a relatively uniform amount of energy from day to day. This energy in the

¹ The Influence of Inanition on Metabolism. Carnegie Institution of Washington, 1907. Publication No. 77.

² Experiment No. 75 on S. A. B., pp. 188, 483, and 496.

fasting animal is supplied mainly by the katabolism of protein and fat. In the intermediate stages of fasting, as has been shown, the katabolism is largely that of fat, but the ratio between fat and protein katabolized may differ widely according to circumstances. In other words the protein requirement, or at least the amount of protein used, may vary, while the energy requirement remains nearly constant. The fasting organism requires a definite quantity of energy, but seems more or less indifferent as to its source.

THE ENERGY REQUIREMENT FOR MAINTENANCE.

In the fasting animal the store of potential energy in the body is diminished daily by the amount required to carry on the vital activities, this amount being, as just shown, relatively constant. In order to prevent such a loss and maintain the store of body energy, it is evident that a corresponding quantity of energy must be supplied in the feed and that a maintenance ration is one which supplies this requisite quantity.

REPLACEMENT OF NUTRIENTS.

For this purpose experiments have shown that the various digestible nutrients may replace each other or the ingredients of the body through a very wide range.

FEED FAT AND BODY FAT.

Fat fed to a previously fasting animal diminishes or suspends the loss of body fat. The following averages of Pettenkofer and Voit's experiments,¹ computed from Atwater and Langworthy's digest,² may serve to illustrate this substitution of feed fat for body fat:

Replacement of body fat by feed fat—Pettenkofer and Voit.

Food.	Number of experiments.	Gain or loss by body.	
		Nitrogen.	Fat.
None.....		Grams.	Grams.
100 grams fat.....	5	-6.64	- 97.76
350 grams fat.....	2	-4.90	- 16.25
	1	-7.70	+113.60

The smaller amount of fat not only diminished the protein katabolism but also largely reduced the loss of fat from the body. While the larger amount of fat showed a tendency to increase the protein katabolism, it not only suspended the loss of body fat but caused a storage of fat in the organism. Of course there is no means of distinguishing in such a case between feed fat and

¹ Zeitschrift für Biologie, vol. 5, p. 370.

² U. S. Department of Agriculture, Office of Experiment Stations, Bulletin 45.

body fat, but it is most natural to suppose that the resorbed fat of the feed, being already in circulation in the body, is more easily accessible to the active cells than the stored-up fat of the adipose tissue and is therefore metabolized in preference to the latter.

CARBOHYDRATES AND BODY FAT.

Experiments precisely similar to those on fat just described show that carbohydrates may also diminish or suspend the loss of body fat. This may be illustrated by the results of three experiments upon a dog by Rubner.

Replacement of body fat by carbohydrates—Rubner.

Food.	Total nitrogen of excreta.	Total carbon of excreta.	Gain or loss of fat.
	Grams.	Grams.	Grams.
None.....	1.94	38.18	-40.99
76.12 grams cane sugar.....	1.45	43.19	- 8.41
104.97 grams cane sugar.....	1.07	47.78	+ .51
None.....	1.42	26.47	-28.10
42.96 grams starch.....	1.53	33.28	-10.54
None.....	2.00	31.53	-32.10
57.38 grams starch.....	1.52	39.67	-10.74

CARBOHYDRATES AND FEED FAT.

Rubner substituted dextrose for fat in the diet of a dog receiving also a fixed amount of lean meat. The results of this substitution are given in the following table, and show that with the larger amount of dextrose in place of the fat previously fed the loss of body fat was prevented:

Replacement of feed fat by carbohydrates—Rubner.

Ration.	Feed per day.			Gain or loss by animal.	
	Meat.	Fat.	Dextrose.	Nitrogen.	Carbon.
	Grams.	Grams.	Grams.	Grams.	Grams.
Meat and fat.....	300	42	.....	+1.81	+1.27
Do.....	300	50	.....	+ .10	+9.31
Meat and dextrose.....	300	.....	63.7	+1.78	-7.44
Do.....	300	.....	79.7	+2.28	-8.15
Do.....	300	.....	115.5	+1.98	+6.21

FEED PROTEIN AND BODY FAT.

It has already been shown that body protein may replace body fat in the katabolism of the fasting animal. A similar substitution of feed protein for body fat may take place. When protein is given to a previously fasting animal it is a well-known fact that the nitrogen of the protein is rapidly split off and excreted, while the nonnitrogenous portion of the molecule serves as a source of energy

to the organism. (Compare pp. 78 to 82.) This nonnitrogenous residue can be substituted for body fat, as is illustrated in an experiment by Rubner in which extracted lean meat was given to a fasting animal, with the result tabulated below:

Replacement of body fat by protein—Rubner.

	Nitrogen of food.	Nitrogen katabo- lized.	Fat katab- olized.
	Grams.	Grams.	Grams.
Fasting.....	0	5.25	84.39
Fed.....	35.22	26.37	28.37
Difference.....		+21.12	-56.02

FAT OR CARBOHYDRATES AND PROTEIN.

A certain minimum of protein is essential to the maintenance of the protein tissues of the body, but feed protein in excess of this amount undergoes rapid katabolism and serves substantially as a source of energy. Such an excess of protein in the feed can be replaced by nonnitrogenous nutrients, particularly the carbohydrates. This effect of fat or carbohydrates as a substitute for protein may be illustrated by the following tabulation of the average results of a number of Pettenkofer and Voit's experiments:

Replacement of feed protein by fat or carbohydrates—Pettenkofer and Voit.

Rations.	Feed per day.				Gain or loss by body.	
	Meat.	Fat.	Starch.	Grape sugar.	Nitrogen.	Carbon.
	Grams.	Grams.	Grams.	Grams.	Grams.	Grams.
Protein only:						
Series I.....	1,500				0	+ 3.3
Average of all (22 experiments).....	1,500				+0.6	+ 8.7
Protein and fat:						
100 grams fat (1 experiment).....	500	100			+ .3	+27.1
200 grams fat (5 experiments).....	500	200			- .6	+67.3
Protein and carbohydrates:						
Starch (8 experiments).....	500	5.3	200		-1.8	+ 9.0
Grape sugar (3 experiments).....	500			200	-1.3	+ 7.2

It appears, then, that all the principal nutrients may serve to supply energy to the body, and the facts just considered show a remarkable degree of flexibility on the part of the animal organism as regards the nature of the material which can be utilized for its metabolism. Aside from the small minimum of protein required, the metabolic activities of the body may be supported now at the expense of the stored body fat, now by the body protein, and again by the protein, the fats, or the carbohydrates of the feed. Whatever may be true economically, physiologically the welfare of the mature animal is not conditioned upon any fixed relation between the classes of nutrients in its feed supply apart from the minimum requirement for protein.

AVAILABILITY OF ENERGY.

Since the chief function of the feed, aside from a minimum of protein, is to supply energy, it would be natural to suppose that the quantity of energy liberated in the body by the oxidation of any given substance (i. e., its metabolizable energy) would be the measure of its nutritive value. If one gram of starch, for example, can liberate 4.2 calories of energy in the body and a gram of fat 9.5 calories, apparently the relative values of the two should be in proportion to these figures. But while the metabolizable energy of the feed represents the maximum amount of energy which can be extracted from it by the organism, it does not follow that all of it can be utilized for maintenance. Energy is not something which can be fed into the organism regardless of its source, like fuel under a boiler. Whatever energy is in essence, so far as the animal is concerned it is carried as chemical energy by the compounds of the feed, and these must be such as can take part in the actual chemical changes occurring in the cells if their energy is to be utilized. The body can not, like a heat engine, avail itself of energy in the kinetic form. It is quite conceivable that a compound might be resorbed from the digestive tract and then simply oxidized to get rid of it without its entering into the cell metabolism. Its energy would be metabolized, that is, converted into the kinetic form, but it would be simply a source of heat and not of other forms of energy. Somewhat similar is the case of the chemical changes occurring in the digestive tract. Some of these, notably the fermentations of the feed, set free energy as heat, yet this energy plays no part in the actual metabolism of the tissues. It is clear, then, that we are not warranted in concluding that because, for example, a fasting animal breaks down body substance equivalent to 10 therms per day, therefore a ration containing 10 therms of metabolizable energy will suffice to maintain the animal. That will depend upon how completely the body is able to use the 10 therms of metabolizable energy supplied to it. In other words, the energy must not only be present, but it must be available energy.

If the metabolizable energy were all available to protect body tissue from oxidation, then giving feed to a fasting or partially fasting animal would be practically the substitution of one kind of fuel for another, and the total heat production would remain the same. It is, however, an observation as old as the time of Lavoisier that the consumption of feed tends to increase the heat production of an animal. That investigator observed the oxygen consumption of man to increase materially (about 37 per cent) after a meal, and subsequent experiments by a large number of investigators have fully confirmed these earlier results, so that the fact of an increased metabolism consequent upon the ingestion of feed is undisputed. It is especially to the investigations of Zuntz and his associates that we

owe the unquestionable demonstration of this fact and of its significance in relation to the nutritive values of feeding stuffs.

These relations may perhaps be more clearly apprehended through an illustration taken from actual experimental work.

AVAILABILITY FOR CATTLE.

In an experiment by Armsby and Fries¹ a steer averaging 373.7 kilograms live weight was fed daily 3.2 kilograms of timothy hay, an amount known to be insufficient for maintenance. The potential energy contained in the feed, the losses in the various excreta, and the metabolizable energy of the ration were determined, with the following results:

<i>Per day and head.</i>	
Feed:	Therms.
3.199 kilos timothy hay-----	12.618
Excreta:	Therms.
4.786 kilos feces-----	5.247
3.943 kilos urine-----	.627
0.079 kilo methane-----	1.057
Total -----	6.931
Metabolizable energy of ration-----	5.687

A balance experiment with the respiration calorimeter showed, as was expected, that the steer was living in part at the expense of his own tissues, the total loss of protein and fat being equivalent to 2.377 therms² per day.

In the period immediately following this one the same steer ate per day 5.194 kilograms of the same timothy hay, all the other conditions of the experiment being as nearly identical as possible. The metabolizable energy of this larger ration, determined in the manner just indicated, was 9.262 therms,³ while a balance experiment showed that the loss of protein and fat had been reduced to the equivalent of 0.357 therm.³

The following comparison of the two periods can therefore be made:

Available energy of timothy hay.

	Ration.		Energy of fat and protein lost by animal.
	Kilos.	Therms.	Therms.
Timothy hay.....	5.294	9.262	0.357
Do.....	3.199	5.687	2.377
Difference.....	2.095	3.575	2.020

¹ Bureau of Animal Industry, Bulletin 128, pp. 177 and 184.

² Computed to 12 hours' standing.

³ Corrected to the same live weight as in Period III.

On the lighter ration, the steer supplemented the energy derived from its feed by 2.377 therms derived from the katabolism of its own fat and protein, but when 2.1 kilograms of timothy hay was added to the ration, the amount of energy which had to be furnished by the body tissues was reduced to 0.357 therm. In other words, 2.1 kilograms of timothy hay supplied 2.020 therms of energy which was available to support the necessary bodily activities and which, therefore, could replace an equal amount which would otherwise have been derived from the katabolism of body substance. This was the contribution which this amount of hay made to the maintenance of the steer.

But the 2.1 kilograms of timothy hay added to the ration supplied, as the table shows, 3.575 therms of metabolizable energy. Clearly, then, a unit of metabolizable energy supplied by the digestible matter of the hay was less efficient than the same amount supplied by body substance. Only 56.5 per cent of it could be substituted for that previously supplied by the katabolism of the fat and protein of the body of the steer, while the remaining 1.555 therms, or 43.5 per cent, simply increased the heat production of the animal, the latter being as follows:

Daily heat production.¹

	Therms.
On the heavier ration-----	9.619
On the lighter ration-----	8.064
	1.555

It is customary in such a case to speak of the 2.020 therms as the available energy of the hay added to the basal ration of Period III and to say that 56.5 per cent of the metabolizable energy of the hay was available. Such a method of statement does not necessarily imply that the remaining 43.5 per cent served no useful function in the body, but simply asserts that the net result to the organism was the same as if 56.5 per cent of the metabolizable energy were substituted unit for unit for energy derived from the katabolism of body substance and as if the remaining 43.5 per cent were useless. What the experiment really shows is that a unit of metabolizable energy in the hay had only 56.5 per cent of the value for maintenance of a unit of metabolizable energy in the body substance (chiefly fat) previously katabolized, but the first method of expression is both common and convenient and may be retained.

Experiments by the same authors on several other feeding stuffs have given results of the same general character as those just quoted. Of the metabolizable energy of these feeding stuffs, as directly determined in each ex-

¹ Corrected to 12 hours standing.

periment, the following percentages were found to be available in the above sense, while the remainder simply served to increase the heat production:

Average availability of metabolizable energy.

	Per cent.
Timothy hay, 5 experiments.....	56.32
Clover hay, 2 experiments.....	58.47
Corn meal, 1 experiment.....	69.12
Wheat bran, 2 experiments.....	55.36
Mixed grain (1 part wheat bran, 3 parts corn meal, 3 parts linseed meal O. P.), 4 experiments.....	57.42

Kellner's¹ extensive investigations upon the metabolism of fattening cattle have likewise demonstrated that in the productive feeding of these animals only part of the metabolizable energy supplied in excess of the maintenance ration is recovered in the gain produced, the remainder being converted into heat, so that the heat production increases with the amount of feed consumed.

AVAILABILITY FOR THE HORSE—ZUNTZ AND HAGEMANN'S RESULTS.

The foregoing results upon cattle have been cited because they illustrate simply and clearly the basic conception of the availability of feed energy and also because they are, so far as the writer is aware, the first experiments upon farm animals on submaintenance rations in which the complete balance of matter and of energy for 24 hours has been determined. Zuntz and Hagemann², however, had shown several years before in an extensive investigation that the increased metabolism which Zuntz and his associates had observed in dogs and men as resulting from the ingestion of food was even more marked in the case of the horse.

In their investigations the respiratory exchange of the animal was determined by the Zuntz method in short periods at various intervals after the consumption of more or less diverse rations, a small correction being added for cutaneous and intestinal respiration. By combining these results with those of a number of separate digestion trials in which the nitrogen and carbon of the feed and of the visible excreta were determined, an approximate determination of the total energy metabolism of the animal was also possible.³

For example, on the average of a number of experiments in which the metabolism shortly before feeding in the morning, shortly after feeding, and some hours later was determined by the methods just outlined, the following results, computed per kilogram per minute were obtained.⁴

	Oxygen consumed.	Energy liberated.
	c. c.	Gram-calories.
Fasting.....	3.339	16.929
36 minutes after feeding.....	3.648	18.510
3½ hours after feeding.....	3.704	18.787

¹ Die Landwirtschaftlichen Versuchs-Stationen, Band 53, and Ernährung der Landwirtschaftlichen Nutztier.

² Landwirtschaftliche Jahrbücher, vol. 27, Ergänzungsband III.

³ For a more complete account of the method, compare Armsby, Principles of Animal Nutrition, pp. 386-387.

⁴ Loc. cit., p. 282.

It was also found that coarse fodder (hay) produced a much more marked effect than did grain. The following comparison of the average of the experiments of period *c* on an exclusive hay diet with that of the experiments of period *f* on a mixed ration illustrates this fact.¹

	Period c.	Period f.
Time since last fed.....hours..	2.6	2.8
Ration:		
Hay.....kilos..	About 10.5	4.75
Oats.....do.....		6.00
Straw.....do.....		1.00
Total digested nutrients (fat × 2.4).....grams..	4,125	5,697
Per kilogram and minute:		
Oxygen consumed.....cubic centimeters..	3.9837	3.6986
Carbon dioxide given off.....do.....	3.6586	3.6695
Energy set free (computed).....gram-calories..	19.552	18.339
Energy katabolism per day and head.....calories..	12,450	11,678

DIGESTIVE WORK FOR CRUDE FIBER.

Zuntz and Hagemann estimate the fuel value of the total digestible nutrients in the feed of the horse (including digestible crude fiber and digestible fat × 2.4) at 3.96 calories per gram, and on the basis of experiments on man made by Magnus-Levy in Zuntz's laboratory they assume that 9 per cent of the metabolizable energy of the digestible nutrients as thus computed is expended in their digestion. The hay ration of the foregoing table contained 1,572 grams less of (estimated) digestible nutrients than the mixed ration. The corresponding expenditure of energy in the digestion of these nutrients (9 per cent of their metabolizable energy) equals 580 calories. Accordingly the energy katabolism should have been 580 calories less in period *c* than in period *f*. It was actually 772 calories greater, a difference of 1,352 calories. This difference is ascribed to the presence in the hay ration of 648 grams more of total crude fiber and corresponds to 2.086 calories per gram of the latter.

WORK OF MASTICATION.

The foregoing computations relate to the expenditure of energy in the digestion of the food after it has entered the stomach. The same authors have also determined the increase in the gaseous exchange caused by mastication, deglutition, etc. For this purpose they compare² the excretion of carbon dioxide and the consumption of oxygen during the time actually occupied in eating with the corresponding amounts during rest, as shown by the average of a number of experiments made under identical conditions. On the assumption that the protein metabolism is unaltered, the amounts of carbohydrates and fat metabolized and the corresponding amounts of energy are calculated. The following is a summary of the results computed per kilogram of feed:

Energy expended in mastication of 1 kilogram—Zuntz and Hagemann.

Feed.	Number of experiments.	Oxygen consumed.	CO ₂ excreted.	Equivalent energy.
		Liters.	Liters.	Calories.
Oats and cut straw (6:1).....	8	12.964	10.679	64.17
Hay.....	8	33.840	27.813	167.44
Hay, oats, and cut straw.....	8	20.072	17.677	100.79
Maize and cut straw (6:1).....	2	7.133	6.205	35.72
Green alfalfa.....	7	6.171	4.980	30.42
Computed for oats alone.....				47.00
Computed for maize alone.....				13.80

¹ Loc. cit., pp. 276-279.

² Loc. cit., p. 271.

As was to have been expected, the work of mastication proves to be much greater in the case of hay than in that of grain. Maize gave a remarkably low result, while the lowest was obtained with green fodder. Even when the results on the latter are computed per kilogram of dry matter, they are still about 40 per cent lower than those on hay. A few experiments on old horses with defective teeth gave somewhat higher results for the mixture of oats and cut straw.

While pointing out that, as the above results show, other factors than the amount of crude fiber influence the work of mastication, they nevertheless believe that a sufficiently close approximation for practical purposes may be reached by computing the work of mastication upon the amount of crude fiber present, which gives an average of 0.565 calorie per gram, and using this factor to compute the work of mastication of the average ration. Adding this factor to the 2.086 calories computed for the work of digestion of one gram of fiber gives a total of 2.65 calories per gram of total crude fiber as representing the work of mastication together with the extra expenditure of energy in digestion.

COMPUTATION OF AVAILABLE ENERGY.

In brief, then, Zuntz and Hagemann compute the available energy, or maintenance value, of a feeding stuff for the horse as follows: First, the metabolizable energy is computed at the rate of 3.96 calories per gram of total digestible matter, including the digestible crude fiber and the digestible fat multiplied by 2.4. Second, from the metabolizable energy thus computed there is subtracted 9 per cent for the work of digestion and in addition 2.65 calories for each gram of total crude fiber present.

The method of computation may be conveniently illustrated from the data given by Langworthy¹ for timothy hay. Zuntz and Hagemann's factors, recalculated per pound for convenience, become, for metabolizable energy, 1.796 therms; for crude fiber, 1.202 therms. On this basis the calculation of the available energy of the hay would be as follows:

Available energy in 100 pounds of timothy hay.

Digestible nutrients:	Pounds.
Protein	1.25
Crude fiber	12.39
Nitrogen-free extract	21.29
Fat (1.18×2.4)	2.83
	37.72
Total crude fiber	29.00
	Therms.
Metabolizable energy (1.796 therms×37.72)	67.75
Work of digestion:	Therms.
9 per cent of metabolizable (67.75 therms×0.09)	6.10
Additional for crude (1.202 therms×29)	34.86
Total	40.96
Available energy (maintenance value)	26.79

¹ U. S. Department of Agriculture, Office of Experiment Stations, Bulletin 125, p. 14.

As is evident from the brief description given of the methods by which the factors are reached, this method of computation is not claimed by its authors to be scientifically exact, but they believe it to be a sufficiently close approximation on which to base computations of rations in practice.

Zuntz and Hagemann's conclusions have been subjected to considerable criticism, the two principal points being, first, their estimate of 9 per cent for the work of digestion, based upon the results of experiments on man; and, second, and more especially, the assumption that the metabolism for 24 hours may be computed from the results of comparatively short respiration experiments. Qualitatively, Zuntz and Hagemann have clearly demonstrated the very considerable expenditure of energy by the horse in the digestion of his feed, as well as the fact that this expenditure is much greater with coarse fodders than with grain, and they were the first to point out that this expenditure of energy must be taken account of in estimating the values of feeding stuffs. There may be a difference of opinion as to the quantitative worth of their figures, and certainly investigations by more direct methods, involving fewer assumptions and complex calculations, are greatly to be desired, but until such results are obtained we may continue to use provisionally those reached in the manner just described.

AVAILABILITY FOR THE HORSE—WOLFF'S RESULTS.

His extensive investigations upon the working horse, made at Hohenheim in 1877 to 1894¹ and antedating the investigations thus far mentioned, led Wolff to a still simpler approximate method of estimating what in a sense corresponds to the available energy of the feed of the horse.

In Wolff's experiments, the horse performed a measured amount of work which was so adjusted in different periods as to be as nearly as possible in equilibrium with the feed consumed. This was considered to be the case when the live weight of the animal remained substantially unchanged for a considerable period and when the urinary nitrogen did not show an increase as a consequence of the additional work done. By comparing the work performed on a basal ration with that which could be done with a heavier one, the ratio of the work done to the additional feed consumed was established within the limits of error of the method, this being the prime object of the experiments. This being determined, however, it was a simple matter to compute the amount of feed corresponding to the total work done, while subtracting this from the total ration would give the maintenance ration. The results of these comparisons, made on the basis of the so-called "digestible nutrients" of the rations (the digestible fat being multiplied by 24) are considered on subsequent pages.

On the average of a considerable number of comparisons, it was found that the digestible nutrients from coarse fodders were less

¹ Compare pp. 57 to 62.

efficient both for work production and for maintenance than were those derived from grain, and Wolff also cites the results of Grandeau and Le Clerc's experiments in Paris which show the same general result. Wolff shows, however, that if the digestible crude fiber be omitted from the comparisons, the ratio between fiber-free nutrients and the work performed is comparatively uniform and also that this assumption yields uniform results for the fiber-free nutrients required for maintenance. He therefore concludes that the crude fiber in the rations of the horse is apparently valueless and that the remaining digestible nutrients may be regarded as of equal value whether derived from grain or from coarse fodders. Expressed in the light of our present conceptions, this is practically equivalent to saying that the expenditure of energy in digestion is proportional to the metabolizable energy of the crude fiber, or that the available energy is proportional to the amount of fiber-free nutrients.

Wolff is careful to say that the digestible crude fiber is *apparently* valueless, and virtually regards the amount of crude fiber as furnishing a convenient empirical measure of the difference in the nutritive value of the digestible nutrients of coarse fodder as compared with those of grain. That such is the case is doubtless explained in part by the rather limited variety of feeding stuffs employed in the experiments. The coarse fodder was meadow hay, with, in some cases, a small addition of straw, while the grain was usually oats, partially replaced in some cases by other feeds. Whether the same relation between fiber-free nutrients and work done would hold in widely different rations is not apparent.

It should be borne in mind that in reality Wolff's results are relative only. They do not show the actual amount of available energy in the feed or ration, but only that it is proportional to the fiber-free nutrients. The energy of the latter would differ considerably from the available energy as computed by Zuntz and Hagemann's method, first, because it does not include the deduction of 9 per cent for digestive work; and, second, because it assumes a uniform value of zero for crude fiber, while Zuntz and Hagemann's method gives the crude fiber a negative value if it has a digestibility of less than 55 per cent. The values computed according to Wolff's method from the fiber-free nutrients are therefore considerably higher than Zuntz and Hagemann's figures.

AVAILABILITY FOR CARNIVORA.

For many years it was taught, in accordance with Rubner's theory of "isodynamic replacement" (compare p. 72), that with carnivora the nutrients were of value in proportion to their content of metabolizable energy. Rubner's own later investigations,¹ however, have

¹ Die Gesetze des Energieverbrauchs bei der Ernährung.

shown that what is true of the feeding stuffs consumed by horses and cattle is also true of nearly pure nutrients fed to dogs. With these subjects it is possible to use the fasting state as the basis of comparison, which considerably simplifies the investigations. The experiments were made at a comparatively high temperature, namely, about 33° C., a fact which is of importance, as will appear later, in the interpretation of the results.

An experiment in which nearly enough fat was fed to supply the requirements of the organism for energy gave the following results per kilogram live weight, stated in a form which is somewhat different from that used by Rubner but which in substance is identical with it:

Availability of energy of fat—Rubner.

	Metabolizable energy of feed per kilogram live weight.	Loss by body per kilogram live weight.
Fat fed.....	Calories. 53.4	Calories. 7.5
Fasting.....	0	54.0
Difference.....	53.4	46.5
Percentage available.....	87.08	

This result appears somewhat remarkable in view of the fact that the comparison is virtually with body fat. Literally interpreted, it means that the energy of feed fat is only 87 per cent as valuable as the energy of body fat plus a little protein. If this be true, it implies a larger expenditure of energy in the digestion of fat than now seems probable, since the katabolism of resorbed feed fat can hardly differ greatly from that of body fat. Rubner's figure is the result of a single experiment and unfortunately it enters into the computation of all the other results. A redetermination of this factor is much to be desired.

In two other experiments, lean meat nearly equivalent to the maintenance requirement was fed. The meat contained a small amount of fat, the average metabolizable energy of the feed per kilogram live weight being distributed as follows:

	Calories.
In protein.....	56.70
In fat.....	4.95
	61.65

Using the data afforded by the experiment on fat, the availability of the energy of the protein may be computed as follows:

Availability of energy of protein—Rubner.

	Metabolizable energy of feed per kilogram live weight.	Loss by body per kilogram live weight.
	Calories.	Calories.
Meat fed.....	61.65	8.90
Fasting.....	0	51.50
Difference.....	61.65	42.60
Difference due to fat.....	4.95	4.31
Difference due to protein.....	56.70	38.29
Percentage available.....	Per cent. 67.53	

The difference between the percentage available and 100 shows, of course, the proportion of the metabolizable energy of the feed which was expended in increasing the total metabolism as measured by the heat production. This increase of the metabolism of the body is called by Rubner the "specific dynamic effect" of the several nutrients. Rubner's final average results are contained in the following table. It should be clearly understood that they are not applicable to the "digestible nutrients" of the feed of herbivora.

Average availability—Rubner.

	Availability.	Specific dynamic effect.
	Per cent.	Per cent.
Body protein.....	68.1	31.9
Meat protein.....	69.1	30.9
Gelatin.....	72.0	28.0
Fat.....	87.3	12.7
Cane sugar.....	94.2	5.8

CAUSES OF INCREASED METABOLISM.

The foregoing paragraphs have dealt with the fact of the increased metabolism and consequent heat production resulting from the ingestion of feed without considering the cause of the increase. Two explanations of it naturally suggest themselves. The first is that the greater supply of the various nutrients directly stimulates the metabolism of the body cells, while the second ascribes the increased metabolism to the additional expenditure of energy required for the digestion of the feed and its preparation for metabolism in the actual vital processes. The latter explanation is the one which has been generally accepted, although by no means without dissent.¹

¹ Compare Heilner, Zeitschrift für Biologie, vol. 48, p. 144; vol. 50, p. 488.

and the expenditure of energy for these purposes has been somewhat loosely and perhaps not altogether fortunately designated as the "work of digestion." A consideration of some of the processes connected with the consumption of feed which lead to the liberation of energy may serve to clarify the conception.

MECHANICAL WORK.

Digestion requires more or less mechanical work in the prehension and mastication of the feed and in moving it through the digestive organs. In this connection, too, it should be remembered that the feed in this sense includes the water as well, three or four parts of water being usually consumed by herbivora for each part of dry matter in the feed. As noted on p. —, Zuntz and Hagemann have compared the metabolism of the horse while eating with that of the same animal while at rest and computed from the difference the amount of energy expended in mastication. The following recapitulation of some of their results shows the number of calories of energy expended in the mastication of 1 kilogram of the material named:

	Calories.
Hay.....	167.5
Green alfalfa.....	30.4
Oats.....	47.0
Maize.....	13.8

Kellner¹ has investigated the effect of the grinding of straw upon its value in a productive ration. He finds that the practical elimination in this way of the work of mastication reduces the expenditure of energy by approximately 0.66 calorie for each gram of crude fiber present in the straw.

That the movement of the masticated feed through the digestive tract must also require an expenditure of energy is obvious, but no data are available as to its amount.

SECRETION.

The secretion of the digestive fluids likewise requires some expenditure of energy. This has been shown by direct experiment to be true of the salivary glands and the pancreas and is also true, doubtless, of the other digestive glands. Apparently, however, the amounts of energy thus expended are comparatively small.

FERMENTATION.

The extensive fermentations occurring in the digestive tract of herbivora result in a considerable evolution of heat. The most important of these is the methane fermentation. Assuming on the basis of Tappeiner's results² that 100 grams of carbohydrates yield 4.7 grams of methane and 33.5 grams of carbon dioxide, and assuming further that two-thirds of the carbon of the organic acids produced is contained in acetic acid and the remainder in butyric, it may be computed that the heat evolved amounts to 12.5 per cent of the total energy of the digested carbohydrates or 0.523 calorie per gram. It should be noted that this estimate does not refer to the potential energy carried off in the methane, but to the heat evolved in the fermentation. The latter is part of the metabolizable energy of the carbohydrates, since it is liberated in the

¹ Die Ernährung der Landwirtschaftliche Nutztier, 5th ed., p. 163.

² Zeitschrift für Biologie, vol. 20, p. 52.

kinetic form in the body, but since it takes at once the form of heat, it is not available energy in the sense in which the term is here used.

The same general considerations, of course, apply to the other fermentations and putrefactions which occur in the digestive tract, but their amount in herbivora is probably small compared with that of the methane fermentation, and we have relatively little knowledge regarding them.

DIGESTIVE CLEAVAGES.

It is well known that extensive cleavages of the feed ingredients occur in the digestive tract. The nutrients, by the action of the digestive ferments, are split up into simpler atomic groupings—the so-called building stones of the molecule—out of which the proteins, carbohydrates, and fats peculiar to the animal body are built up. One argument which has been brought forward in the past against the extensive occurrence of such cleavages in natural digestion, especially of the proteins, has been the teleological one that the splitting up into these comparatively simple compounds was a waste of valuable nutritive material. On the other hand these processes have been invoked to explain the striking effect of the proteins in stimulating the metabolism—their large specific dynamic effect, to use Rubner's terminology. So far as the peculiar use of protein in the body is concerned, it is well established that its crystalline cleavage products can be resynthesized to form protein. It is of special interest, therefore, to learn that these cleavages and resyntheses are apparently nearly isothermic processes. Some of the cleavage products of protein contain more potential energy per gram than protein itself, as, for example, leucin, with 6.525 calories per gram, and tyrosin, with 5.916 calories per gram. Others, like alanin, with a heat of combustion of 4.356 calories, contain but little less energy than the protein from which they are derived. Even the simplest amino-acid, glycocol, resulting from this cleavage has a heat of combustion of 3.129 calories per gram. The impression which these figures give—that but little energy is lost in the cleavage of the proteins—is confirmed by direct experiments. Loewi¹ found the dry residue of the tryptic digestion of meat to have an energy value of 4.6 calories per gram. Tangl, Lengyel, and Hari² found the products of the peptic or tryptic digestion of egg albumin and serum albumin to contain nearly or quite as much potential energy as the original protein. Grafe³ has made artificial digestions of protein in a calorimeter, and found no noticeable evolution or absorption of heat. It seems safe, therefore, to regard the digestive cleavage of protein as at least a nearly isothermic process, causing little loss of energy in digestion.

Substantially the same thing is true of the digestive cleavage of carbohydrates and fats. Thus 1 gram of starch yields 1.111 grams of dextrose, and the heats of combustion of these quantities are, respectively, 4.183 calories and 4.159 calories, showing a loss of less than 0.6 per cent. One gram of sucrose yields 0.5264 gram each of dextrose and levulose, and the energy values are, respectively, 3.955 calories and 3.947 calories, or a loss of less than 0.2 per cent. So, too, 1 gram of tristearin with a heat of combustion of 9.43 calories yields by hydrolysis 0.9573 gram of stearic acid, equivalent to 9.026 calories, and 0.1033 gram of glycerin, equivalent to 0.424 calorie, or a total of 9.45 calories.

¹ Leathes. Problems in Animal Metabolism, p. 129.

² Archiv für die gesammte Physiologie des Menschen und der Thiere (Pflüger), vol. 115, p. 1.

³ Jahresbericht über die Fortschritte der Tier Chemie, vol. 37, p. 917.

INTERMEDIARY METABOLISM.

The chemical reactions taking place during the so-called intermediary metabolism of the resorbed material before it is finally utilized for the vital processes have also to be considered as possible sources of heat production, although our present knowledge of them is meager.

This possibility is of special interest in connection with the marked effect of protein on the energy metabolism, since this can hardly be ascribed to digestive work in the strict sense. In the normal digestion of protein fermentations play a very small part, while, as just shown, the digestive cleavage of protein is substantially isothermic. Neither can we imagine that the mechanical work of digestion or the secretion of digestive juices can account for the large expenditure of energy. Rubner¹ has reported experiments in which the protein katabolism of the fasting animal was artificially increased by the administration of phlorhizin, and in which a similar increase in the heat production is computed, although there could have been no digestive work in the strict sense. Falta, Grote, and Stählein² have found that the products of the tryptic digestion of casein when fed to a dog produce nearly as great an increase in the metabolism as does a corresponding amount of casein, while in the familiar experiments of Zuntz and Mering³ the intravenous injection of the crude products of the peptic digestion of blood fibrin had a like effect.

The katabolism of protein seems to consist in outline, first, of a hydrolytic cleavage into peptids and amino-acids and, second, in a deamidization of these latter compounds, and it is the nonnitrogenous products resulting from this deamidization which serve as a source of energy for the body, the nitrogen being split off as ammonia and excreted as urea. It is to a liberation of energy in the form of heat in these preliminary processes of preparing protein to serve as fuel that Rubner and other authors ascribe its specific dynamic effect.

Our knowledge of the intermediary metabolism of protein is too meager to render any quantitative estimate of the amount of energy lost in this way of much value. The cleavage of protein, as noted, seems to be substantially isothermic. The deamidization of the simpler amino-acids with a small number of carbon atoms seems at first thought to involve considerable loss of energy. For example, the potential energy of 1 gram of glycocol and of alanin and of equivalent amounts of acetic and propionic acids are:

	Glycocol.	Alanin.
	Calories.	Calories.
Energy of amino acid.....	3.129	4.356
Energy of equivalent fatty acid.....	2.791	4.129
Difference.....	.338	.227
Percentage loss.....	10.8	5.2

A similar comparison of alanin with the equivalent amount of lactic acid shows an apparent loss of about 14 per cent. With the higher members of the series, the loss computed in this way is relatively small. It must be remembered, however, that the amino group is split off as ammonia, which also con-

¹ Gesetze des Energieverbrauchs bei der Ernährung.

² Beiträge zur Chemischen Physiologie und Pathologie, vol. 9, p. 372.

³ Archiv für die gesammte Physiologie des Menschen und der Thiere (Pflüger), vol. 32, p. 199.

tains potential energy equal, according to Ostwald, to 3.319 calories per gram in the gaseous state. If we assume that the alanin yields lactic acid with a heat of combustion of 3.7 calories per gram we may make the following comparison:

	Calories.	Calories.
Energy of 1 gram alanin.....	4.356	
Energy of 1.011 grams lactic acid.....	3.742	
Energy of 0.191 gram ammonia.....	0.634	
	4.376	
Difference.....	.020	

In other words, it would appear that the deamidization of the amino acids, like the antecedent cleavage of the proteins, is a nearly isothermic reaction and that we must seek elsewhere for the explanation of the specific dynamic effect of protein. We can by no means assert, however, that the protein katabolism actually takes place according to this simple scheme, nor that the nonnitrogenous substances resulting from deamidization of the amino acids yield their energy without loss. It seems not unlikely that the higher fatty acids and other nonnitrogenous derivatives of protein are broken down by cleavage and otherwise to comparatively simple molecules before they are finally oxidized, and there is the possibility of more or less loss of energy in such processes.

As already indicated, Rubner explains the specific dynamic effect of protein from the foregoing point of view, but in a different manner. It has been shown beyond reasonable doubt that sugar is produced, or may be produced, in the katabolism of protein. According to Rubner, it is only the energy of this sugar that is capable of being used for the physiological functions of the body cells, while the energy set free in the conversion of protein into sugar is liberated as heat and constitutes the specific dynamic effect. This explanation of Rubner's, however, seems to be disproved by recent results reported by Lusk and Ringer.¹ They have shown that alanin is completely convertible to dextrose in a diabetic animal, while in the case of glutamic acid but three out of the five carbon atoms of the molecule are utilized for the production of dextrose. According to Rubner's hypothesis, therefore, alanin should show no specific dynamic effect, while glutamic acid should show a considerable one. In a preliminary communication Lusk² reports that neither one of these amino acids when added to a standard diet increased the excretion of carbon dioxide in the respiration. This result is in striking contrast with those of Falta, Grote, and Stählein and of Zuntz and Mering just referred to, in which the crude products of tryptic or peptic digestion were fed. They suggest that some substance other than the recognized amino-acids may be responsible for the stimulating effect of protein upon metabolism, while they likewise recall the fact that crude peptones have been found to have a poisonous effect when injected intravenously while purified peptones do not, and likewise the fact that in Zuntz and Mering's experiments purified peptones caused no increase in the metabolism.

EXCRETION.

Zuntz³ calls attention to Barcroft's⁴ experiments, which show that the excretory activity of the kidneys is accompanied by a notable increase in the amount of oxygen consumed, and sees in the work thrown on these organs by the elimination of the nitrogen of protein one of the causes of its specific

¹ Journal of the American Chemical Society, vol. 32, p. 671.

² Proceedings of Society for Experimental Biology and Medicine, 1910, vol. 7, p. 136.

³ Medizinische Klinik, 1910.

⁴ Ergebnisse der Physiologie, vol. 7, p. 744.

dynamic effect. In experiments in collaboration with Steck he found that a marked increase of the metabolism, as computed from the oxygen consumed, followed the administration of urea, and likewise of sodium chlorid, to men and dogs. In the case of urea he computes that the effect was equal to 20 to 25 per cent of that of an equivalent amount of protein. Zuntz also calls attention to earlier experiments by Nering and Schmoll in which carbohydrates added to the diet of a diabetic produced a similar increase of metabolism, although the sugar was not assimilated but excreted unchanged. Zuntz ascribes the results obtained by Rubner to the fact that phlorhizin added largely to the increased excretory work required by the elimination of the nitrogen and of the sugar formed, pointing out also that Rubner has overestimated the amount of heat produced through failure to deduct the energy of the sugar excreted in the urine. On the other hand, in Lusk's experiments, just quoted, there was an increased excretion of urea subsequent to the administration of amino acids, but no increase in the carbon dioxide excreted, while Tangl¹ finds that the intravenous injection of urea or sodium chlorid causes an increase in the metabolism even when the kidneys have been extirpated or clamped off.

On the whole, it can not be said that any fully satisfactory explanation has yet been offered of the effects of feed, and in particular of protein, upon the metabolism, although certain factors, especially in domestic animals, are clearly evident.

But whatever explanation we may accept—whether, following Zuntz, we speak of work of digestion, or, with Rubner, avoid any implication as to the cause by the use of the term specific dynamic effect—the fact that the metabolizable energy of different feeding substances is not equally available for maintenance is established beyond question, and it is this fact which is of immediate importance in considering the energy requirement for maintenance and the maintenance values of feeding stuffs.

THE MAINTENANCE RATION.

In accordance with the principles laid down in the foregoing paragraphs, a maintenance ration as regards energy may be defined as one which supplies available energy equal to the fasting katabolism.

For example, in Rubner's experiment cited on page 27, in which fat was fed, the fasting katabolism of the dog was 54 calories per kilogram. Fat containing 53.4 calories of metabolizable energy diminished the loss of body tissue by 46.5 calories. Evidently, then, to reduce the loss by 54 calories, that is, to reduce it to zero, would have required $53.4 \times \frac{54}{46.5} = 62$ calories of metabolizable energy to be supplied in fat. The same thing may also be expressed in a slightly different way: If, as there computed, only 87.08 per cent of the metabolizable energy of fat is available, then to make good a total loss of 54 calories will require $54 \div 0.8708 = 62$ calories of metaboliza-

¹ Biochemische Zeitschrift, vol. 34, p. 1.

ble energy in fat.¹ On this basis we may compute from Rubner's final averages (p. 28) that to maintain the dog experimented on, that is, to make good the loss of 54 calories of energy per kilogram, it would have been necessary to supply per kilogram the following amounts of metabolizable energy in the materials named:

	Calories.
In meat protein.....	79.3
In gelatin.....	78.1
In fat.....	61.9
In cane sugar.....	57.3

These figures afford a simple illustration of the fact that the amount of metabolizable energy required for maintenance is variable, being greater as its availability is less. The maintenance requirement of the dog was 54 calories of available energy. The maintenance ration needed to supply this varied according to the material which served as the carrier of the energy.

The same relations hold good for farm animals, although the fact that we can not well observe their fasting katabolism directly makes the computation a trifle more complicated. As an example, we may take the experiment on timothy hay already cited on page 20. The addition of 2.1 kilograms of timothy hay, equivalent to 3.575 therms of metabolizable energy, to the basal ration reduced the loss of energy from the body of the animal by 2.020 therms. Evidently, then, to have reduced it by 2.377 therms, that is, to zero, would have required the addition of $2.1 \times \frac{2.377}{2.020} = 2.471$ kilograms of the hay, equivalent to 4.207 therms of metabolizable energy. The total maintenance ration of this particular feeding stuff, then, would have been the basal ration plus this amount, or 5.670 kilograms of the hay, equivalent to 9.894 therms of metabolizable energy.

The same result may also be obtained by the use of the percentage availability as computed, viz, 56.5 per cent. The heavier ration failed to maintain the animal by 0.357 therms, that is, it lacked this amount of available energy. To supply this requirement would evidently demand $0.357 \div 0.565 = 0.632$ therms of metabolizable energy, which added to the 9.262 therms already contained in the ration gives a total as above of 9.894 therms. The same computation can, of course, be made from the lighter ration with the same result.

From the data given it is likewise possible to compute what the loss by the body would have been had it been practicable to withdraw all feed. The basal ration contained 5.687 therms of metabolizable energy, of which 56.5 per cent was available; that is, the basal ration was capable of preventing the loss of $5.687 \times 0.565 = 3.213$ therms from

¹ On the assumption, of course, that the effect is a linear function of the amount of food.

the body. Had the basal ration been entirely withdrawn, then the loss would have been increased by this amount; that is, the total loss would have been $3.213 + 2.377 = 5.590$ therms. The same quantity would, of course, be obtained by starting from the heavier ration or from the maintenance ration as computed above. The fasting katabolism, which can not well be determined directly, is thus obtained by computation. In other words, this steer expended daily 5.590 therms of energy in the maintenance of his necessary vital processes aside from those connected with the digestion and assimilation of his feed. This was his maintenance requirement as defined in the foregoing paragraphs, and an amount of the clover hay which was capable of supplying this quantity of available energy, viz, 5.670 kilograms, was a maintenance ration, while on smaller amounts he drew upon his body tissues to cover the deficiency.

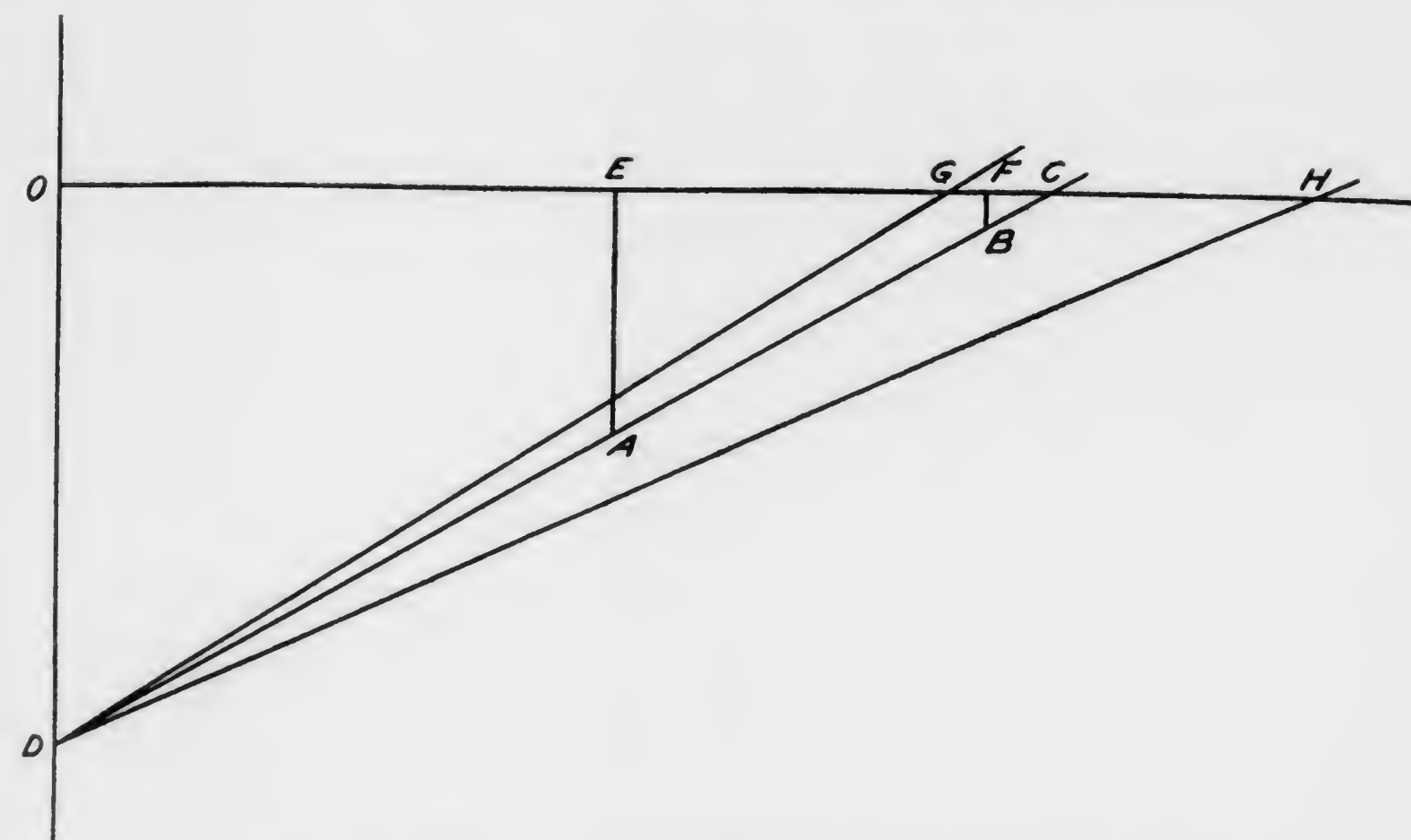


FIG. 1.—Availability of metabolizable energy of hay.

All these facts may also be conveniently represented graphically as follows:

If on the two coordinate axes of figure 1, we let the horizontal distances represent the metabolizable energy of the feed and the vertical distances the gain of energy by the body of the animal, the results of the two experiments just referred to may be represented by the points A and B, the distances OE (equal to 5.687 therms) and OF (equal to 9.262 therms) representing the amounts of metabolizable energy in the two rations and the distances EA (equal to -2.377 therms) and FB (equal to -0.357 therm) the corresponding (negative) gains of energy by the animal. A straight line drawn through A and B and intersecting the two axes at D and C will then represent the relation between the supply of metabolizable energy in the feed and the gain by the body of the animal.¹ This relation may also be expressed analytically by the equation $y = ax - m$, in which $m = OD$ (equal to 5.590 therms) will represent the com-

¹ Assuming that this is a linear function.

puted fasting katabolism and α the tangent of the angle between AB and the horizontal axis (equaling in this case 0.565), or the percentage availability, while OC (equal to 9.894 therms) is the maintenance ration in terms of the metabolizable energy of this particular hay.

The fasting katabolism being a constant quantity under like conditions, it follows that an amount of any feed capable of supplying 5.590 therms of available energy would have been a maintenance ration for this animal. It is clear then that the actual weight of feed required for maintenance will vary inversely as the availability of its energy. With this particular hay, it would have been necessary to use an amount containing 9.894 therms of metabolizable energy. With the timothy hay used in an earlier experiment, however, 62.9 per cent of whose metabolizable energy was found to be available, corresponding to the line DG in figure 1, it would have been necessary to use a quantity containing only $5.590 \div 0.629 = 8.888$ therms, represented in the figure by OG, in order to supply the requisite available energy and secure maintenance. On the other hand, with a coarser forage having, e. g., an availability of only 45 per cent, represented by DH, it would have been necessary to supply $5.590 \div 0.45 = 12.420$ therms of metabolizable energy, represented in the figure by the line OH. Just as was illustrated previously in the case of the dog, while the real requirement of energy for the vital processes remains unchanged the amount of feed necessary for maintenance is variable, depending upon the availability of its energy.

If with Zuntz we regard the increased katabolism consequent upon taking feed as representing energy expended in its digestion and assimilation, we may state the case in a slightly different way. We may compare the work thus done to the work of placing the fuel under a factory boiler. If this is done by means of power derived from the same boiler, it is evident that the farther the fuel has to be moved and the greater the amount of incombustible waste which it contains, the larger will be the fraction of the total boiler power required simply to keep the fire going and the less the proportion available for running the factory. So in the body, the greater the amount of energy which must be expended on the food in order to prepare it for its functions in the body the less is the proportion of its energy which is available for carrying on the physiological processes.

RELATION OF MAINTENANCE REQUIREMENT TO LIVE WEIGHT.

Before taking up the specific maintenance requirements of farm animals, it is necessary to consider the influence of size and weight upon the maintenance requirement.

That large animals katabolize more matter and produce more heat than smaller ones requires no special proof. Experiment shows, however, that the difference is not proportional to size or weight, but that small animals have a relatively more intense metabolism than large ones, the amount being approximately proportional to the body surface, which, of course, is relatively greater in the smaller animal. The existence of such a relation was surmised by various writers, but we are indebted to Rubner¹ for the first quantitative investigation of this question. He determined the fasting katabolism of six dogs whose weights ranged from 3 to 24 kilograms. With the addition of earlier experiments by Voit on a still larger dog, the average results were as follows, the total katabolism being expressed in terms of computed energy.

Relation of fasting katabolism to weight and to surface—Rubner and Voit.

No. of animal.	Live weight.	Katabolism per kilogram, live weight.	Katabolism per square meter of body surface.
	Kilos.	Calories.	Calories.
I.....	30.66	36.66	1.046
II.....	23.71	40.91	1.112
III.....	19.20	45.87	1.207
IV.....	17.70	46.20	1.097
V.....	9.51	65.16	1.183
VI.....	6.44	64.79	1.120
VII.....	3.10	88.25	1.214

While not mathematically constant, the ratio between the fasting katabolism and the surface shows a close approximation to uniformity, and the same fact has been verified by a considerable number of subsequent experiments. Moreover, it has been shown² to be approximately true not only of animals of the same species, but of animals ranging in size from man to domestic fowls, and including also cold-blooded animals. A recent investigation by Kettner³ upon 13 guinea pigs furnishes a striking illustration of this general uniformity.

Rubner explains the apparent dependence of the fasting katabolism on body surface as the consequence of the loss of heat from the body due to the cooling action of the environment, which would naturally be proportional to the surface. The fact, however, that not inconsiderable variations have sometimes been observed indicates that other factors than the elimination of heat are concerned, and apparently the true cause lies deeper. Not merely the heat production but all the important physiological activities of the body, including the expenditure of energy in locomotion, seem to be proportional to the

¹ Zeitschrift für Biologie, vol. 19, p. 535.

² E. Voit. Zeitschrift für Biologie, vol. 41, p. 113.

³ Archiv für (Anatomie und) Physiologie, 1909, p. 447.

body surface rather than to the weight, while the fact that the same law holds true for cold-blooded animals, which assume the temperature of their surroundings and which, therefore, are subjected to no demand for heat, points in the same direction. Apparently we have here a general biological law of which the proportionality between heat production and body surface is one expression.

The internal work of the animal, however, as measured by the fasting katabolism or the fasting heat production, constitutes, as we have seen, its maintenance requirement. The maintenance requirements of animals of different sizes, therefore, especially of those of the same species, are proportional to their surfaces.

COMPUTATION OF RELATIVE BODY SURFACE.

Few actual determinations of the body surface of animals have been made and almost none for farm animals, so that it is at present impossible to express with accuracy the metabolism of the latter animals per unit of surface. For purposes of comparison between individuals of the same species, however, another method serves to give at least approximate results. It is a familiar geometrical fact that the surfaces of two solids of the same shape (i. e., similar figures in the geometrical sense) are proportional to the two-thirds powers of their volumes. By regarding all animals of the same species as of the same shape and also as having the same specific gravity, so that their weights are proportional to their volumes, it is a very simple matter to compute their relative surfaces and the corresponding maintenance requirements. For example, a steer weighing 583 kilograms was found to have a computed fasting katabolism (i. e., maintenance requirement) of 8.671 therms. A steer weighing 500 kilograms, other things being equal, would have a maintenance requirement in proportion to its smaller surface. The latter would be to the surface of the larger animal, approximately, as $(500)^{\frac{2}{3}}$ is to $(583)^{\frac{2}{3}}$ and the maintenance requirement would therefore be $8.671 \times \left(\frac{500}{583}\right)^{\frac{2}{3}} = 7.878$ therms. In this way it is a simple matter to compute the relative maintenance requirements of different individuals without the necessity of expressing them per unit of surface.

Of course, such a comparison is only approximately correct. In the first place, it may be presumed that there are differences in the specific gravity of different individuals, although it may be doubted whether these differences are sufficiently great to be of much significance in this connection. Moreover, different animals are not of the same shape. The young animal differs in conformation from the older one, and the beef steer and the dairy cow, for example, are far from being geometrically similar. It would be of much interest to determine the relation of surface to weight in different species, types, and ages of domestic animals, but lacking such determinations the

method of computation above outlined may probably be assumed to give a fair approach to the truth and is at any rate the only one available.

THE MAINTENANCE RATIONS OF FARM ANIMALS.

In endeavoring to formulate the maintenance rations of farm animals it is important to have a clear conception of the nature of the problem and to distinguish between its physiological and its economic aspects. The physiological conception of the maintenance requirement is the amount of energy required to carry on the absolutely necessary vital processes in a state of the most complete rest possible. It is the least amount on which life can be sustained; the physiological minimum; the base line for comparison. In actual practice, no such state of complete rest can be maintained for any length of time. There is necessarily superadded to the minimum physiological requirement the energy expended in a variety of ways, but especially in the numerous minor muscular movements which are unavoidable in the waking state, which may be summarized under the term incidental work. Some of the factors of this incidental work are discussed on subsequent pages. Physiologically, this additional energy is expended for production; the animal is doing work on its surroundings. Economically, however, the work done is of no value and the energy required to do it is, therefore, from that point of view, a part of the cost of maintenance. In practice, of course, it is not the physiological but the economic requirement which is of importance. The latter will necessarily be more or less variable according to the individuality of the animal and the conditions under which it is maintained, as will appear in the following discussion, and statements of maintenance requirements and rations should therefore indicate to such a degree as is possible the conditions to which they are intended to apply.

CATTLE.

The maintenance requirements of cattle have been more extensively studied than those of other species and it will be convenient to take them up first, using the data also as a means of illustrating the principles involved and the methods of investigation employed.

The estimate of the maintenance ration of cattle long current and still occasionally cited was based upon the investigations of Henneberg and Stohmann¹ in 1858. According to their results, a 1,000-pound steer required for maintenance about 8.16 pounds of digestible organic matter per day, equivalent to about 14.3 therms of metabolizable energy. In view of the rather high stable tem-

¹ Beiträge zur Begründung einer rationellen Fütterung der Wiederkäuer, Heft I, pp. 17-188.

perature in these experiments, however, Wolff¹ when formulating his well-known feeding standards increased this amount to 9.1 pounds digestible organic matter, equivalent to about 15.9 therms of metabolizable energy. Numerous subsequent experiments,² however, showed quite clearly that this estimate was considerably too high but without affording a sufficient basis for its correction, and it is only since 1898 that really satisfactory data have been secured.

One general method of experimentation has already been illustrated in the computation on pages 34-35 of the maintenance requirement of a steer. In brief, it consists of comparing the losses of body energy by the animal when fed two different amounts of the same feed or combination of feeds, each being less than the maintenance ration, and computing from the difference the amount of energy required for simple maintenance.

Investigations by Armsby and Fries³ include eight trials with three different animals substantially upon this plan. In the later experiments of the series a correction was made for differences in live weight in the different periods of each experiment and for differences in the amount of time spent standing and lying, the results being computed to 12 hours standing. The results here given for the earlier experiments have been corrected in the same manner and therefore differ somewhat from those originally reported. The following tabulation of the results shows also, for comparison, the percentage availability of the metabolizable energy of the feed and likewise the maintenance ration expressed in terms of metabolizable energy. The results in every case have been computed to a uniform live weight in proportion to the two-thirds power of the weight. It is to be noted that the experiments are upon coarse fodder (clover and timothy hay) exclusively, and that the animals were not fat.

Maintenance requirements and rations of steers—Armsby and Fries.

Years.	Animal.	Available energy for maintenance.		Percentage availability of metabolizable energy.	Metabolizable energy for maintenance.		Feed.
		Per 500 kilograms live weight.	Per 1,000 pounds live weight.		Per 500 kilograms live weight.	Per 1,000 pounds live weight.	
1903.....	I	Therms. 6.483	Therms. 6.076	Per cent. 50.88	Therms. 12.742	Therms. 11.942	Clover hay.
1904.....	I	7.812	7.321	80.24	9.736	9.124	Do.
1905.....	A	6.649	6.231	60.51	10.988	10.297	Timothy hay.
1905.....	B	7.532	7.058	55.21	13.642	12.784	Do.
1906.....	A	6.077	5.695	[57.05]	10.652	9.982	Do.
1906.....	B	6.806	6.378	[56.50]	12.046	11.288	Do.
1907.....	A	5.186	4.860	57.05	9.090	8.519	Do.
1907.....	B	6.931	6.496	56.50	12.267	11.497	Do.
Average of all.....		6.685	6.264	59.24	11.395	10.679	
Average, omitting 1904.....		6.523	6.113	56.24	11.632	10.901	
Average, 1905-1907.....		6.531	6.121	57.14	11.447	10.728	

¹ Landwirtschaftliche Fütterungslehre, 2d ed., 1877, pp. 132 and 196.

² The Maintenance Ration of Cattle, Pennsylvania Experiment Station Bulletin 42, pp. 12-21.

³ Bureau of Animal Industry, Bulletins 74, 101, and 128. The results reported in Bulletin No. 51 can not be computed directly in this way because the ration included a small fixed amount of linseed meal.

Omitting the results of the year 1904, which are obviously too high both as regards the maintenance requirement and the percentage availability, we obtain the following averages in round numbers:

	Available energy.	Metabolizable energy.
	Therms.	Therms.
Per 500 kilograms live weight.....	6.52	11.63
Per 1,000 pounds live weight.....	6.11	10.90

The variations from these averages which occur in individual cases illustrate the fact, already pointed out, that the economic as distinguished from the physiological requirement may vary considerably with different animals and under different conditions.

The experiments just cited are the only ones thus far reported in which this precise method of determining the maintenance requirement in terms of available energy has been followed. In the majority of investigations the effort has been to feed as nearly an exact maintenance ration as possible, making a correction for the small gains or losses by the animals, and the results of these experiments have usually been expressed in terms of metabolizable energy.

By far the most exact and satisfactory experiments of this sort, as well as the earliest, are those reported by Kellner from the Moeckern Experiment Station¹ in 1894 and 1896, in which the gain or loss of protein and fat (nitrogen and carbon balances) was determined by means of a Pettenkofer respiration apparatus. In these experiments the feed consisted exclusively of coarse fodder, viz, meadow hay, or, in two instances, a mixture of clover hay and oat straw. In six cases out of the eight the respiration experiments showed a small gain of protein and fat by the animal; that is, the ration was somewhat above the maintenance requirement. For example, the gains by ox A on meadow hay and the computed equivalent amounts of energy were:

	Material gained.	Equivalent energy.
	Grams.	Therms.
Protein.....	37.2	0.211
Fat.....	140.8	1.338
Total.....		1.549

In later investigations by Kellner, out of 100 units of metabolizable energy of meadow hay supplied in excess of the maintenance requirement, only 43 were recovered in the protein and fat gained by the body. To produce the gain observed in this experiment, therefore, may be computed to have required $1.549 \div 0.43 = 3.602$ therms of metabolizable energy and the ration must have contained this amount in excess of the maintenance ration. The following calcu-

¹ Die Landwirtschaftlichen Versuchs-Stationen, vol. 44, p. 370; vol. 47, p. 310; vol. 53, pp. 6-16.

lation, therefore, shows the amount of metabolizable energy of meadow hay which was necessary for the maintenance of the animal:

Energy of feed.....	Therms.
Energy of feces.....	32.177
Energy of urin.....	11.750
Energy of methane.....	1.945
Energy of total excreta.....	2.114
	15.809
Metabolizable energy of ration.....	16.368
Metabolizable energy equivalent to gain.....	3.602
Metabolizable energy for maintenance.....	12.766

This method of computing the metabolizable energy necessary for maintenance is obviously the same in principle as that employed in Armsby and Fries's experiments, differing only in the fact that the comparison is made on amounts of feed exceeding the maintenance ration. Kellner's results, however, can not be made the basis of a direct computation of the available energy required for maintenance, since it appears probable that a larger percentage of the energy of hay is available below the point of maintenance than is utilized for gain above it.¹

In two cases (ox B and ox IV) the rations were less than the maintenance ration and the animals lost more or less protein and fat. In computing these experiments Kellner, in accordance with the ideas then generally accepted, simply added the energy equivalent to the loss of tissue to the total metabolizable energy of the feed to obtain the maintenance ration. It is evident, however, from what has subsequently been learned regarding the availability of metabolizable energy, as outlined in the foregoing paragraphs, that if, for example, ox B lost tissue equivalent to 1.498 therms it would have required more than this amount of metabolizable energy in the food to make good the loss, the quantity necessary depending upon the availability of the energy. Of the latter we have no determinations for this particular ration, but for purposes of computing a correction we may, perhaps, assume it to be the same as that found by Armsby and Fries for timothy hay, viz, about 57 per cent. On this assumption the equivalent amount of metabolizable energy which would have had to be supplied to reach the maintenance ration of ox B would have been $1.498 \div 0.57 = 2.628$ therms, a difference of 1.130 therms. For ox IV the corresponding correction is only 0.740 therm.

Making these slight changes in Kellner's original figures for these two animals for the sake of uniformity, his results are as follows:

¹ Compare Bulletin 128, Bureau of Animal Industry, p. 59.

Maintenance rations of oxen—Kellner.

	Live weight.	Stable temperature.	Maintenance ration (metabolizable energy).		
			Per head.	Per 500 kilograms.	Per 1,000 pounds.
Thin animals:	Kilos.	° C.	Therms.	Therms.	Therms.
Ox V.....	602.1	14.7	11.675	10.316	9.668
Ox B.....	611.5	15.9	17.966	15.709	14.721
Ox A.....	619.8	15.9	12.766	11.060	10.365
Ox IV.....	622.8	14.9	15.861	13.701	12.840
Ox III.....	632.1	14.7	13.284	11.352	10.639
Ox II.....	632.4	15.0	14.457	12.362	11.585
Ox VI.....	644.0	14.8	11.771	9.944	9.320
Ox XX.....	671.7	16.5	15.213	12.486	11.702
Average.....			14.124	12.116	11.355
Average, omitting ox B.....			13.575	11.603	10.874
Fat animals:					
Ox I.....	748.0	15.9	23.449	17.93	16.80
Ox B.....	750.0	15.2	19.385	14.79	13.86
Ox 3.....	858.0	16.1	22.162	15.46	14.49
Average.....			21.656	16.06	15.05

The observed maintenance ration of ox B is notably larger than that of the other animals. This animal refused to lie down during the respiration experiments and presumably, therefore, the result obtained with it is abnormally high.

Omitting this result, the maximum, minimum, and average maintenance rations per 1,000 pounds live weight were:

Metabolizable energy required for maintenance of cattle per 1,000 pounds live weight—Kellner.

	Per 1,000 pounds live weight.
Thin animals:	Therms.
Maximum.....	12.84
Minimum.....	9.32
Average.....	10.87
Fat animals:	
Maximum.....	16.80
Minimum.....	13.86
Average.....	15.05

If we are justified in assuming, on the basis of Armsby and Fries's results, that approximately 57 per cent of the metabolizable energy of these rations was available, then the foregoing amounts of metabolizable energy are equivalent to the following amounts of available energy:

Computed available energy required for maintenance of cattle—Kellner.

	Per 1,000 pounds live weight.	Per 500 kilograms live weight.
For thin animals:	Therms.	Therms.
Maximum.....	7.32	7.81
Minimum.....	5.31	5.67
Average.....	6.20	6.61
For fat animals:		
Maximum.....	9.58	10.22
Minimum.....	7.75	8.42
Average.....	8.58	9.15

Both the averages and the range of the results obtained by Kellner and by Armsby and Fries for thin cattle on coarse fodder show a remarkably close agreement. The results upon fat cattle will be considered on subsequent pages.

In addition to the respiration experiments just considered, a number of live-weight experiments upon the maintenance ration of cattle have been reported.

Such trials were made by the writer at the Pennsylvania Experiment Station¹ in 1892 to 1897, the feed being either chiefly or entirely coarse fodder. The live weight was taken daily during relatively long periods and the nitrogen balance was also determined, and from these data an approximate computation of the loss of fat was attempted. The amount of methane excreted, and the corresponding loss of metabolizable energy, was calculated from the total carbohydrates digested. Computing the final results on the same assumptions as in the Moeckern experiments,² the results of 4 experiments each on 3 animals weighing from 400 to 500 kilograms, computed per 500 kilograms live weight, were:

Metabolizable energy in maintenance rations of steers—Armsby.

Ration.	Per 500 kilograms live weight.		
	Steer 1.	Steer 2.	Steer 3.
Chiefly or entirely coarse fodder:			
Experiment I, 1892-93.....	Therms. 14.23	Therms. [17.09]	Therms. 13.69
Experiment II, 1892-1894.....	13.61	13.56	12.40
Experiment VI, 1894-95.....	12.92	12.87	12.73
Experiment VII, 1894-95.....	13.03	12.76	[17.77]
Averages (omitting results in brackets).....	13.45	13.06	12.94
Largely grain:			
Experiment VIII.....	11.72	9.15	10.70

Assuming, as before, that about 57 per cent of the metabolizable energy was available, and omitting the two apparently exceptional results, the maximum, minimum, and average results are:

Ration.	Metabolizable energy.		Available energy.	
	Per 500 kilograms live weight.	Per 1,000 pounds live weight.	Per 500 kilograms live weight.	Per 1,000 pounds live weight.
Coarse fodders:				
Maximum.....	Therms. 14.23	Therms. 13.34	Therms. 8.11	Therms. 7.60
Minimum.....	12.40	11.62	7.07	6.62
Average.....	13.15	12.32	7.50	7.02
Largely grain.....	10.52	9.86	6.00	5.62

The results on coarse fodders are materially higher than those of the respiration experiments just cited, but the method is, of course, much less accurate.

Haecker³ reports determinations of the maintenance rations of dry cows made in three successive years and in which three different animals were used. In these experiments the nutrients digested were determined directly and the sufficiency of the ration judged of from the live weight and appearance of the animals. Results obtained by Kellner⁴ and by Armsby and Fries⁵ show that

¹ Pennsylvania Experiment Station, Bulletin 42.

² This differs somewhat from the method of computation followed in the original report of the experiments.

³ Minnesota Experiment Station, Bulletin 79.

⁴ Die Landwirtschaftlichen Versuchs-Stationen, vol. 53, pp. 440-445.

⁵ Bureau of Animal Industry, Bulletins 51, 74, 101, and 128.

the metabolizable energy does not vary greatly from 1.6 therms per pound (3.5 therms per kilogram) of total digestible organic matter, even in rations differing widely as to the kinds of feed used. From the data regarding the digestible matter of the rations, therefore, the equivalent amounts of metabolizable energy may be estimated on this basis. Computing the results per 1,000 pounds in proportion to the two-thirds power of the live weight, instead of directly as does Haecker, the results are as follows:

Maintenance rations of dry cows—Haecker.

Cow.	Year.	Average live weight.	Average daily gain in live weight.	Kind of feed.	Metabolizable energy.	
					Per head.	Per 1,000 pounds live weight.
		Pounds.	Pound.		Therms.	Therms.
Alice.....	1896-97	808	0	Corn fodder.....	7.92	9.13
Belle.....	1896-97	1,010	0		9.26	9.19
Average.....						9.16
Belle.....	1897-98	1,072	0.27	Corn fodder, beets, and oil meal.	10.16	9.71
Lottie.....	1897-98	706	.27		7.01	8.83
Lottie.....	1898-99	757	.16		8.96	10.75
Average.....						9.76
Average of all.....						9.51

In the first year's experiments the amount of digestible protein fed was small and the condition and appearance of the animals were not satisfactory. In the second and third years the rations were richer in protein, a slight gain in live weight was made, and the condition of the animals was entirely satisfactory at the close of the experiment. Since some gain was made in the second and third years the amount consumed was naturally somewhat larger than the first year. The proportion of grain to coarse fodder in the rations is not stated, but the results of the digestion trials indicate that it must have been small. If we assume 60 per cent availability, the computed available energy of the rations per 1,000 pounds live weight is:

	Therms.
Maximum.....	6.45
Minimum.....	5.30
Average of all.....	5.71

The results as thus computed run materially lower than those obtained at Moeckern and at the Pennsylvania station, in spite of the fact of a gain in live weight.

Evvard¹ fed three yearling steers for 60 days and one for 362 days on rations so adjusted and varied as to very exactly maintain their live weight, the average daily gain or loss being practically negligible. The experiment in the case of the first three animals followed a 30-day period in which a submaintenance ration was fed and the animals were therefore only in medium condition.²

The rations fed differed from those of the experiments previously quoted in containing a much larger proportion of grain, consisting of 4 parts by weight of alfalfa hay and 10 parts of mixed grain.³ Evvard computes the available

¹ Thesis for degree of M. S., University of Missouri, 1909.

² The animals graded in the maintenance period as follows: No. 500, common; No. 598, common; No. 596, good to medium; No. 595, medium.

³ Eight-ninths corn chop and one-ninth old process linseed meal.

energy of the rations consumed from the data given in Bulletin 71 of the Pennsylvania station with the following results:

Maintenance rations of yearling steers—Evvard. (First experiment.)

No. of animal.	Length of experiment.	Average live weight.	Estimated available energy per day.	
			Per head.	Per 1,000 pounds ¹ live weight.
	Days.	Pounds.	Therms.	Therms.
590	60	608	5.63	7.85
598	60	461	3.85	6.45
596	60	464	4.34	7.25
595	362	609	5.83	8.09

¹ Computed in proportion to the two-thirds power of the live weight.

In addition to the uncertainty attaching to such live-weight experiments, as well as to the fact that the available energy was estimated, there is also a special difficulty in determining the true maintenance requirement of growing animals, which will be referred to later. Nevertheless, the results appear to agree fairly well with those obtained in the respiration calorimeter experiments.

The metabolizable energy of the rations, also computed from the data given in Bulletin 71 of the Pennsylvania station, is, on the other hand, lower than that found in either the Pennsylvania or the Moeckern experiments, although agreeing well with Haecker's results on dry cows, viz, per 1,000 pounds live weight:

No.	Therms.
No. 590	10.42
No. 598	8.57
No. 596	9.63
Average	9.54

Evvard's first three animals were also fed a maintenance ration of the same feeds in the same proportions for 120 days after having been previously fed heavier rations for 127 days, during which No. 590 received about one-fourth of full feed, No. 598 about one-half, and No. 596 full feed. The results of this second maintenance period are summarized in the following table:

Maintenance rations of yearling steers—Evvard. (Second experiment.)

No. of animal.	Length of experiment.	Average live weight.	Estimated available energy per day.	
			Per head.	Per 1,000 pounds ¹ live weight.
	Days.	Pounds.	Therms.	Therms.
590	120	706	6.47	8.15
598	120	665	6.44	8.45
596	120	860	9.66	10.62

¹ Computed in proportion to the two-thirds power of the live weight.

The data contained in the foregoing pages may be summarized in the following table showing the maximum, minimum, and average maintenance rations in various experiments. Armsby and Fries's results, as already noted, have been corrected to 12 hours standing. No statement of the amount of time passed standing and lying, respectively, is given in the reports of the other experiments.

Daily maintenance rations of cattle per 1,000 pounds live weight.

Investigators.	Condition of animals.	Number of animals.	Number of single trials.	Metabolizable energy.			Available energy.		
				Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.
Armsby and Fries.	Thin.	3	7	Therms. 12.78	Therms. 8.52	Therms. 10.90	Therms. 7.06	Therms. 4.86	Therms. 6.11
Kellner.	do.	7	7	12.84	9.32	10.87	7.32	5.31	6.20
Do.	Fat.	3	3	16.80	13.86	15.05	9.58	7.75	8.58
Armsby (coarse fodder).	Thin.	3	10	13.34	11.62	12.32	7.60	6.62	7.02
Armsby (much grain).	do.	3	3	10.98	8.57	9.86	6.26	4.88	5.62
Haecker.	do.	3	5	10.75	8.83	9.51	6.45	5.30	5.71
Evvard, 60-day experiment.	do.	3	3	10.42	8.57	9.54	7.85	6.45	7.18
Evvard, 362-day experiment.	do.	1	1			10.74			8.09
Evvard, second experiment.	Partly fattened.	3	3				10.62	8.15	9.07
Average of all experiments.	Thin.	20	36	13.34	8.52	10.50	7.85	4.86	6.31
Average of respiration experiments.	Fat.	6	6			15.05			8.83
	Thin.	10	14	12.84	8.52	10.89	7.32	4.86	6.16

The foregoing results justify the statement that the maintenance ration of thin cattle, expressed in terms of available energy, ranges in general from 5 to 7.5 therms per 1,000 pounds live weight, averaging a little above 6 therms. The maintenance ration of fat animals appears to be distinctly greater than that of thin ones.

It should be noted that the term available energy is used in the sense defined on pages 20-22, as determined by a comparison of experiments upon submaintenance rations. This available energy is not necessarily identical with the energy values in terms of which the values of feeding stuffs and the requirements of animals have been expressed by Kellner and others (compare Farmers' Bulletin 346), since his results were obtained by a comparison of super-maintenance (productive) rations. Such scanty data as are now on record seem to indicate that the two are substantially the same in case of concentrated feeds, but that the available energy of coarse feeds below maintenance may be greater than their productive values above the point of maintenance. If this should prove to be the case, then evidently an estimated requirement of 6 therms of Kellner's production values will give a maintenance ration ample for practical purposes, but which will be a somewhat too large deduction to make in estimating the productive part of the ration.

SHEEP.

Data regarding the maintenance rations of sheep are less complete than for those of cattle. No experiments are on record in which the requirement of available energy has been directly determined, and but few respiration experiments have been made. Most of the recorded data are based upon live-weight experiments.

In 1867-68 Henneberg and his associates¹ conducted a series of respiration experiments upon two mature sheep receiving approximately a maintenance ration of meadow hay. Two digestion experiments, including determinations of the nitrogen balance, were made with each of the animals. During each of these digestion experiments three respiration experiments were made upon the two animals together. The results of these determinations vary so little that their average is sufficient for our present purpose. Estimating, as in some of the experiments on cattle, that each kilogram of digestible organic matter contains approximately 3.5 therms of metabolizable energy, and further, that, as in the case of Kellner's steers, 43 per cent of the metabolizable energy of the feed could be stored up in the form of gain of flesh and fat, the following computation per day and head may be made:

Maintenance ration of sheep—Henneberg and Stohmann.

Live weight, exclusive of wool.....	kilograms..	45.4
Digestible organic matter per day.....	grams..	539.1
Gain by animal:		
Protein.....	do.....	7.95
Fat.....	do.....	13.75
		Therms.
Metabolizable energy of ration 0.5391×3.5		1.887
Metabolizable energy equivalent to gain:		
Protein, $0.00795 \text{ kilo.} \times 5.7$	Therm.	0.0453
Fat, $0.01375 \text{ kilo.} \times 9.5$		.1306
		.1759 $\div 0.43$
Metabolizable energy for maintenance.....		1.478

The foregoing ration is equivalent to 1.574 therms per 50 kilograms, or 1.475 therms per 100 pounds, computed in proportion to the two-thirds power of the live weight.

In 1872 Henneberg, Fleischer, and Müller² began a series of respiration experiments upon sheep in which wheat gluten was added to a basal ration of hay and ground barley. The basal ration of the first period proved to be but slightly greater than the maintenance ration. Making the same calculations as before, but assuming that 50 per cent of the metabolizable energy of the ration might serve for the production of gain, since a portion of the ration consisted of grain, we have the following:

¹ Neue Beiträge, etc., pp. 68-286.

² Jahresbericht der Agriculturchemie, vol. 16-17, II, 145.

Maintenance ration of sheep—Henneberg, Fleischer, and Müller.

Live weight.....	kilograms..	34.20
Digestible organic matter per day.....	grams..	562.94
Gain by animal:		
Protein.....	grams..	1.94
Fat.....	grams..	43.60
		Therms.
Metabolizable energy of ration 0.56294×3.5		1.970
Metabolizable energy equivalent to gain—		
Protein, 0.00194×5.7	Therm.	0.01106
Fat, 0.0436×9.5		.41420
		.42526 $\div 0.50$
Metabolizable energy for maintenance.....		1.119

This result is equivalent to 1.441 therms per 50 kilograms or 1.350 therms per 100 pounds live weight.

Hagemann,¹ from the results of a digestion and metabolism experiment and of 42 short² respiration periods with the Zuntz type of apparatus on a mature sheep averaging 50.33 kilograms live weight, computes an approximate energy balance which may be put in the following form, assuming that 50 per cent of the surplus metabolizable energy of the mixed ration might be recovered as gain:

Maintenance ration of sheep—Hagemann.

	Income.	Outgo.
	Therms.	Therms.
Feed:		
Alfalfa hay.....	2.181	
Corn meal.....	1.524	
Uneaten.....		0.009
Excreta:		
Feces.....		1.332
Urine.....		.146
Gain:		
1.44 grams protein.....	Therm.	0.008
46.20 grams fat.....		.439
		.447 $\div 0.50$
Maintenance.....		.914
		1.304
	3.705	3.705

In addition to the foregoing experiments there are a number of digestion experiments by Wolff, in which the live weight of the animals was approximately maintained. In 1871³ two series of experiments were made upon the relative digestive power of three breeds of sheep for an approximate maintenance ration. A comparison of the live weights of the animals is possible only for the second series, in which the ration consisted of clover hay and potatoes. The total organic matter digested per day and head and the average live weights at the beginning and end of the experiment were as given in the

¹ Archiv für (Anatomie und) Physiologie, 1899, Suppl., p. 138.

² Usually not exceeding 30 to 40 minutes.

³ Landwirtschaftliche Jahrbücher, vol. 1, p. 533.

table, which also shows the metabolizable energy equivalent to the digested organic matter (3.5 therms per kilogram), both per head and per 50 kilograms live weight, computed in proportion to the two-thirds power of the latter. The average result is equivalent to 1.634 therms per 100 pounds live weight.

Maintenance rations of sheep—Wolff.

Breed.	Number of animals.	Live weight. ¹		Digested organic matter per day and head.	Equivalent metabolizable energy per day.	
		Initial.	Final.		Per head.	Per 50 kilograms live weight.
		Kilos.	Kilos.	Grams.	Therms.	Therms.
Electoral merino.....	1	39.85	39.20	345.35	1.209	1.414
	2	42.05	40.50	342.34	1.198	1.361
Natives.....	3	49.85	49.50	537.97	1.883	1.891
	4	47.45	47.20	523.24	1.831	1.898
Southdowns.....	5	67.55	66.20	680.43	2.382	1.963
	6	59.05	59.70	620.38	2.171	1.936
Average.....					1.779	1.744

¹ Average of 5 or 6 consecutive days.

In 1892-93 Wolff¹ made a series of experiments with sheep on the influence of salt upon digestibility. In the first two periods of this series an approximate maintenance ration of 1,000 grams of meadow hay per day and head was fed. Since the salt was found not to affect the digestibility of the feed, we may use the results of the two periods as a basis for computing the maintenance ration. The average live weights per head were as follows:

	January 2, 3, and 4.	February 5, 6, and 7.
Sheep No. 1.....	42.9	44.0
Sheep No. 2.....	43.8	42.8
Sheep No. 3.....	42.8	44.5
Sheep No. 4.....	42.2	42.0
Average.....	42.9	43.3

The feed consumption was uniform with all the animals and the percentage digestibility showed but very slight variations, so that we may regard the average of the eight trials as representing approximately the maintenance ration. The average amount of organic matter digested per day and head was 476.28 grams. Reckoning, as before, 3.5 therms of metabolizable energy per kilogram, this corresponds to 1.667 therms per head, equivalent to 1.841 therms per 50 kilograms or 1.725 therms per 100 pounds live weight, computed in proportion to the two-thirds power of the latter.

Wolff² has also computed the digestible matter in the rations consumed by sheep in a number of the earlier experiments by Henneberg. The average of six rations which appeared amply sufficient for maintaining the live weight of the animal was, per head:

Live weight	Kilograms.
Organic matter digested	40.05
Equivalent metabolizable energy	.566
	therms. 1.981

¹ Landwirtschaftliche Jahrbücher, vol. 25, p. 175.

² Ernährung der Landwirtschaftliche Nutztiere, pp. 416-419.

Computed in the usual way, this is equivalent to 2,300 therms per 50 kilograms. This is a much higher result than was obtained in any of the other experiments, and in view of the fact that the digestibility of the rations was estimated and that the feed was of a somewhat varied character it seems permissible to omit this result from consideration.

The results of the experiments cited, omitting the ones last mentioned, may be summarized as follows:

Daily maintenance rations of sheep.

Kind of experiment, and investigator.	Metabolizable energy.	
	Per 50 kilograms live weight.	Per 100 pounds live weight.
Respiration experiments:		
Henneberg and Stohmann.....	Therms. 1.574	Therms. 1.475
Henneberg, Fleischer, and Müller.....	1.441	1.358
Hagemann.....	1.304	1.222
Average.....	1.440	1.352
Digestion experiments:		
Wolff, 1871, 6 experiments.....	1.744	1.634
Wolff, 1892-3, 8 experiments.....	1.841	1.725
Average.....	1.793	1.680
Average of all.....	1.581	1.483

It is of some interest to compare this average maintenance ration of sheep with the corresponding results for cattle. If we assume that the surfaces exposed by these two species are roughly proportional to the two-thirds powers of their live weights, the corresponding maintenance ration for a 1,000-pound steer would be $1.483 \times \left(\frac{1000}{100}\right)^{\frac{2}{3}} = 6.885$ therms of metabolizable energy as compared with an average of 10.50 therms for cattle. While such a comparison is, of course, but a rough approximation, it nevertheless seems to show conclusively that the metabolism of the sheep per unit of surface is distinctly lower than that of cattle. No obvious reason for such a difference suggests itself. That it can hardly be due to the direct effect of the wool in diminishing the radiation of heat will appear from a discussion, in a later section, of the influence of external temperature on the maintenance requirement.

SWINE.

Two determinations of the fasting katabolism of swine have been reported by Meissl, Strohmer, and Lorenz.¹ The experiments were made with the respiration apparatus, no calorimetric determinations being carried out.

Computing the energy katabolized by the use of Rubner's factors for the energy corresponding to the nitrogen and carbon excreted, the writer² obtained

¹ Zeitschrift für Biologie, vol. 22, p. 63.

² Principles of Animal Nutrition, p. 452.

the figures contained in the third column of the following table. Kellner¹ has recomputed the results, using the exact figures for the carbon, nitrogen, and energy content of the flesh of swine which were obtained by Köhler, with the results shown in the last column.

Fasting katabolism of swine—Meissl, Strohmer, and Lorenz.

	Live weight.	Fasting katabolism.	
		Armsby.	Kellner.
Experiment V.....	Kilos. 140	Therms. 2.607	Therms. 2.737
Experiment VI.....	120	2.291	2.385

Computing Kellner's figures to uniform live weight in proportion to the surface we have:

	Per 50 kilo-grams.	Per 100 pounds.
Experiment V.....	Therms. 1.377	Therms. 1.290
Experiment VI.....	1.333	1.249
Average.....	1.355	1.270

These figures, according to the principles enunciated in the foregoing pages, may be regarded as representing the available energy required for maintenance. No other direct determinations of this requirement appear to have been made.

In addition to the foregoing, a number of live-weight experiments have been reported.

Dietrich² determined the amount of feed required by growing pigs to maintain their live weight at different stages of growth. The trials were made when the animals reached approximately the weights of 50, 100, 150, and 200 pounds, 4 animals being used. The digestibility of the ration fed at the weight of 150 pounds was also determined. The actual average amounts of feed required per day and head were as follows:

Maintenance rations of swine at different ages—Dietrich.

Period.	Average live weight.	Feed required for maintenance.		
		Corn meal.	Mid-dlings.	Skim milk.
I.....	Pounds. 49.62	Pounds. 0.15	Pounds. 0.15	Pounds. 1.2
II.....	98.75	.40	.40	1.6
III.....	151.25	.80	.80	1.6
IV.....	201.37	.67	1.33	.....

¹ Die Ernährung der Landwirtschaftliche Nutztiere, 5th ed., p. 156.

² Wisconsin Experiment Station, 16th Report, 1899, p. 31.

Assuming the composition of the feeding stuffs used to be fairly represented by the averages given in Farmers' Bulletin 22 (revised) and using Jordan's digestion coefficients for middlings, oil meal, and skim milk, and Kellner's coefficients for corn meal, the writer has computed the digestible nutrients contained in the rations consumed with the results shown in the following table. The metabolizable energy of the rations has been computed from the amount of digestible nutrients, using the factors—

	Calories per gram.
Digestible protein.....	4.1
Digestible nitrogen-free extract.....	4.2
Digestible crude fiber.....	3.5
Digestible ether extract.....	8.8

Computed digestible nutrients and metabolizable energy per day—Dietrich's experiments.

Period.	Digestible nutrients per head.			Metabolizable energy.		
	Protein.	Carbohydrates.	Fat.	Per head.	Per 50 kilo-grams live weight.	Per 100 pounds live weight.
I.....	Pounds. 0.065	Pounds. 0.241	Pounds. 0.012	Therms. 0.628	Therms. 1.069	Therms. 1.002
II.....	.126	.561	.028	1.415	1.523	1.427
III.....	.204	1.033	.050	2.556	2.069	1.939
IV.....	.205	1.159	.057	2.817	1.885	1.766

Taylor¹ reports quite similar experiments with animals weighing respectively 50, 100, and 150 pounds. Computed in the same manner as the previous experiments, the results are as follows:

Maintenance rations of swine at different ages—Taylor.

Period.	Average live weight.	Feed required for maintenance.		
		Shorts.	Corn meal.	Oil meal.
I.....	Pounds. 52.1	Pounds. 0.48	Pounds. 0.24	Pounds. 0.08
III.....	103.5	1.14	.57	.19
V.....	157.0	1.20	.60	.20

Computed digestible nutrients and metabolizable energy per day—Taylor's experiments.

Periods.	Digestible nutrients per head.			Metabolizable energy.		
	Protein.	Carbohydrates.	Fat.	Per head.	Per 50 kilo-grams live weight.	Per 100 pounds live weight.
I.....	Pounds. 0.096	Pounds. 0.434	Pounds. 0.025	Therms. 1.105	Therms. 1.821	Therms. 1.707
III.....	.288	1.030	.058	2.618	2.730	2.558
V.....	.240	1.083	.061	2.753	2.174	2.037

¹ Wisconsin Experiment Station Report, 1901, p. 67.

Carlyle¹ reports the average daily food for maintenance of 12 brood sows for eight weeks after weaning their pigs as follows:

Average live weight.....	Pounds.
Feed per day and head:	306
Corn.....	1.49
Shorts.....	1.49
Oil meal.....	.50
Skim milk.....	6.90

The computed digestible nutrients and energy of the above ration are:

Digestible protein.....	Pounds.
Digestible carbohydrates.....	0.654
Digestible fat.....	2.307
Equivalent metabolizable energy:	.117
Per head.....	Therms.
Per 50 kilograms live weight.....	6.079
Per 100 pounds live weight.....	3.077
	2.884

In a preliminary report of experiments upon pig feeding, Dietrich² estimates the maintenance ration of growing pigs per 100 pounds live weight to be:

Digestible crude protein.....	Pounds.
Digestible carbohydrates.....	0.10
Digestible fat.....	.40
	.04

This ration, using the same factors as before for the metabolizable energy, is equivalent to 1.181 therms per 50 kilograms or 1.107 therms per 100 pounds live weight.

The foregoing results show a wide range in the apparent food requirement for the maintenance of live weight. In general, the lower results seemed to have been reached with the younger animals. This may be due, however, to the fact that, as will be shown in a subsequent paragraph, the maintenance of live weight in a young animal is not necessarily synonymous with the maintenance of its store of potential energy. If we omit the results obtained with the 50-pound animals and also omit Dietrich's results at the Illinois Station, since his experiments seem to have been with comparatively young animals, we find the range of results to be as follows:

	Per 50 kilograms.	Per 100 pounds.
Minimum.....	Therms. 1.523	Therms. 1.427
Maximum.....	3.077	2.884
Average.....	2.243	2.102

On the basis of respiration experiments by Meissl as discussed by Kellner,³ four rations consisting of not dissimilar feeds showed

¹ Wisconsin Experiment Station, Bulletin 104, p. 31.

² Illinois Experiment Station, Circular 126, p. 116.

³ Die Ernährung der Landwirtschaftliche Nutztiere, 5th ed., p. 157.

an approximate average utilization of 74.5 per cent of the metabolizable energy supplied in excess of the fasting katabolism. If we may apply this percentage to the average of the foregoing results regarding maintenance, we may compute the average requirement of available energy to be $2.243 \times 0.745 = 1.671$ therms per 50 kilograms, or 1.566 therms per 100 pounds, a result not differing very widely from the figures computed on a previous page from the results of experiments on the fasting katabolism, but with a very wide range of variation in individual cases.

THE HORSE.

The maintenance ration of the horse has been the subject of investigation by Zuntz and Hagemann, Wolff, Müntz, and Grandeau and Le Clerc.

ZUNTZ AND HAGEMANN'S INVESTIGATIONS.

Upon the basis of the results regarding the availability of energy for the horse, which have been described on pages 22-25, Zuntz and Hagemann¹ compute the fasting katabolism of the horse by substantially the same method as that employed on pages 34-35 for cattle.

For this purpose, they use those rest experiments on horse III in which the feed consisted of oats, hay, and straw. From the results of the respiration experiments made within the first five hours after feeding, they compute the total energy katabolism per day in the manner indicated on page 22, and from this subtract the energy expended in the digestion of the feed (not including the work of mastication), computed as shown on page 23. The remainder, of course, is the katabolism due to internal work, together with any katabolism resulting from a possible demand for heat to maintain the body temperature. Their results may be tabulated as follows:

Computed fasting katabolism of horse per day and head—Zuntz and Hagemann's experiments.

	Live weight.	Energy katabolism.	Feed.			Work of digestion.	Fasting katabolism.	Fasting katabolism per square centimeter body surface.	Season.
			Oats.	Straw.	Hay.				
	Kilos.	Therms.	Kilos.	Kilos.	Kilos.	Therms.	Therms.	Gram-calories.	
Period a.....	428.1	12.541	6	1	7	8.403	4.138	80.7	Winter.
Period b.....	434.1	11.674	6	1	6	7.704	3.970	76.7	Summer.
Period c.....	450.4	12.364	6	1	6	7.704	4.600	87.9	Winter.
Period f.....	449.1	11.783	6	1	4.75	6.830	4.953	93.6	Summer.
Period i.....	440.1	11.893	6	1	6	7.704	4.189	80.2	Winter.
Period n.....	448.2	11.407	4.8	0	5.1	5.672	5.735	108.5	Summer.
Period c.....	442.2	12.450	0	0	10.5	7.340	5.110	97.6	Do.
Period No. 118c	434.6	11.021	4.8	0.8	1.88	4.122	6.899	133.3	Winter.

In the experiments with a standard ration of 6 kilograms of oats, 1 of straw, and 6 (or 7) of hay, the average computed fasting katabolism for the three winter periods is 4.329 therms, while in the

¹ Loc. cit., pp. 283-284 and 425-426.

single summer period it reaches the minimum of 3.970 therms. Zuntz and Hagemann consider that the latter represents approximately the minimum requirement for internal work and regard the higher figures obtained in the winter experiments as indicating a stimulation of the heat production by the low temperature to which the animal was exposed. The notably higher results obtained with the lighter rations they ascribe to a similar cause, viz, that the heat arising from the work of digestion and from the necessary internal work (fasting katabolism) was insufficient to maintain the body temperature. Accordingly, they regard the differences shown in column 8 of the foregoing table as including in these cases not only the minimum necessary for internal work but also an expenditure for heat production. In other words, they consider that the critical temperature (compare p. 71) for the horse is high as compared with that for cattle, and the critical amount of food small (compare p. 73). Earlier experiments¹ upon another horse in which lighter rations were fed confirmed this conclusion.

On the average of the 8 most satisfactory experiments out of 12, the estimated total katabolism per day and head was 11.027 therms upon a ration consisting of 3.5 kilograms of oats, 0.5 of straw, and 2.5 of hay. Computed in the same manner as in the foregoing examples, the expenditure of energy in the digestion of this ration is equal to 3.782 therms, which leaves a remainder of 7.244 therms, equivalent to 140.3 gram-calories per square centimeter of surface. This is a higher figure than any of those contained in the foregoing table, although the total katabolism was not notably different. The authors conclude, therefore, that the small amount of heat liberated by the digestive work was compensated for by an increased katabolism of body tissue.

From a balance experiment on the same animal in the respiration apparatus of the Göttingen Experiment Station they also compute² the metabolizable energy required for maintenance by subtracting from the total nutrients digested the fat equivalent of the protein and fat gained by the animal. They thus reach a maintenance ration per 500 kilograms, live weight, of 3.265 grams digestible nutrients, equivalent to 12.93 therms. Their final conclusion (loc. cit., p. 426) is that their animal required per head at least 11 therms, or per 500 kilograms live weight 12.10 therms, of heat to maintain his body temperature. In other words, this is the minimum of metabolizable energy which must be supplied in a maintenance ration, since if less be present, even although the ration supplies the requisite amount of available energy, body tissue will still be katabolized for the production of the heat necessary to maintain the body temperature.

Computed to 1,000 pounds live weight in proportion to the two-thirds power of the latter, Zuntz and Hagemann's maintenance ration is:

	Therms.
Available energy for internal work.....	4.08
Additional required for heat production.....	7.80
Total metabolizable energy required.....	11.88

¹ Landwirtschaftliche Jahrbücher, vol. 18, p. 1; vol. 27, Ergänzungs Band III, pp. 356-257.

² Ibid., p. 423-424.

The maintenance requirement as measured by the computed fasting katabolism is notably less than that of cattle. The same criticisms which have been made of Zuntz and Hagemann's conclusions as regards availability are also applicable, of course, to his computation of the maintenance requirement.

WOLFF'S INVESTIGATIONS.

Wolff has also determined by a different method the maintenance ration of the horse in the experiments whose results as regards the available energy of feeds have already been mentioned on page 25. As there noted, the amount of work performed by the horse was adjusted so as to be as nearly as possible in equilibrium with the feed consumed. Wolff's experiments were made with a sweep power arranged to serve also as a dynamometer. The actual measurements of the work performed, except in the later experiments, proved to be too low; but Wolff believes them to be relatively correct, so that the ratio between the work as measured and the additional feed required to produce it may still serve as the basis of computation.

In the experiments of 1877-1886¹ it was found that the work performed in 100 revolutions of the dynamometer required the addition to the ration of 315 grams of digestible nutrients. It is important to note, however, in view of what follows, that this additional digestible material included no digestible crude fiber—that is, that it was practically derived from the grain added in the periods of heavier work. Subtracting from the total digestible nutrients of the ration, therefore, an amount computed on this basis to be equivalent to the work done leaves a remainder representing the nutrients required for maintenance on the virtual assumption that all the work done was performed at the expense of nutrients derived from the grain. The results of these computations are summarized in the following table:

Maintenance rations of horses—Wolff, 1877-1886.

Animal.	Number of experiments.	Total nutrients.	Nutritive ratio.	Live weight.	Number of revolutions.	Equivalent nutrients.	Maintenance ration by difference.
		Grams.		Kilos.		Grams.	Grams.
Horse I.....	4	6,305.6	1:5.79	521	600	1,890	4,416
Horse II:							
1881-82.....	7	5,831.1	1:6.64	477	546	1,720	4,111
1882-83.....	4	6,748.3	1:6.37	486	662	2,085	4,663
1883-84.....	6	5,920.2	1:7.26	457	567	1,786	4,134
Average.....	17	6,078.4	1:6.80	473	577	1,818	4,260
Horse III:							
1881-82.....	6	5,313.8	1:7.16	454	404	1,273	4,041
1882-83.....	6	6,061.3	1:6.88	469	683	2,152	3,909
1883-84.....	5	5,734.8	1:7.55	473	580	1,827	3,908
1885.....	4	5,761.2	1:7.57	473	575	1,811	3,950
Average.....	21	5,717.8	1:7.29	467	501	1,766	3,952

¹ Grundlagen für die rationelle Fütterung des Pferdes, 1886, 66-155; Neue Beiträge; Landwirtschaftliche Jahrbücher, vol. 16, Ergänzungs Band III, 1-48.

Computed to 500 kilograms live weight on the basis of what Wolff regards as the normal weights of the animals, the foregoing maintenance rations are:

Horse I.....	Grams. 4,143
Horse II.....	4,260
Horse III.....	4,167

A series of similar experiments on horse III, weighing 475 kilograms, in 1885-86,¹ computed in substantially the same way, gave results for the maintenance ration agreeing well with those of earlier years, viz:

Maintenance rations of a horse—Wolff, 1885-86.

Period.	Per head.	Per 500 kilograms.
I.....	Grams. 3,934	Grams. 4,141
II.....	3,984	4,194
III and V.....	4,001	4,212
VIIb.....	4,094	4,310
VIII.....	4,094	4,310
Average.....	4,021	4,232

In a succeeding period (IX), however, in which hay alone was fed, a decidedly higher result was obtained, viz, 4,357 grams per head, or 4,586 grams per 500 kilograms.

In these earlier experiments, in accordance with the views then prevalent, Wolff regarded the so-called nutrients as of equal value whatever their source. The experiment with hay, just mentioned, however, suggested that such was not the case and this suspicion was confirmed by later investigations which clearly showed the superiority of the digestible matter of grain over that of hay. This superiority was not apparent in the earlier experiments because the proportions of grain and coarse fodder were not widely different in the several experiments, the coarse fodder furnishing on the average fully one-half of the dry matter fed.

This difference, suggested by the experiment on hay, was demonstrated by a comparison by Wolff² of his own results with those obtained by Grandean and Le Clerc³ in experiments upon two cab horses receiving only a small amount of walking exercise. The ration used by the latter experimenters consisted of about 75 per cent of grain as against less than 50 per cent in Wolff's experiments, and from it Wolff computes an average maintenance ration per 500 kilograms of 3,626 grams of digestible nutrients as compared with the 4,000 to 4,200 grams of the foregoing table.

Direct experiments by Wolff⁴ likewise show that the digestible nutrients of concentrated feed (oats) are more valuable for work production than those of coarse feed (hay). The experiments were made in the manner already described, the draft being uniformly 60 kilograms. Although the measurements of the work actually done are probably incorrect, it may be assumed to have been substantially proportional to the number of revolutions of the dynamometer. A ration of 3 kilograms of hay and 5.5 kilograms of oats served as the basal ration, to which was added on the one hand 4 kilograms of hay and

¹ Landwirtschaftliche Jahrbücher, vol. 13, Ergänzungs Band III, p. 32.

² Ibid., pp. 73-81.

³ L'Alimentation du Cheval de Trait, 1883, II, 86 and 131.

⁴ Loc. cit., pp. 84-95.

on the other 1½ kilograms of oats. The nutrients digested in each case and the equivalent amounts of work secured were:

Nutrients equivalent to work—Wolff, 1886-87.

Period.	Ration.	Digested.					Equivalent work.
		Protein.	Crude fiber.	Nitrogen-free extract.	Ether extract.	Total (fat × 2.4).	
I-III....	7 kilograms hay, 5.5 kilograms oats.....	Grams. 822.58	Grams. 816.68	Grams. 3,889.64	Grams. 186.72	Grams. 5,973.62	Revolutions. 750
V.....	3 kilograms hay, 5.5 kilograms oats.....	626.46	422.74	3,068.78	184.78	4,561.13	350
	4 kilograms hay.....	196.12	393.94	821.18	1.94	1,412.49	400
	Per 100 revolutions.....					353.12	
VI.....	3 kilograms hay, 7 kilograms oats.....	754.52	355.24	3,719.24	252.17	5,434.21	700
V.....	3 kilograms hay, 5.5 kilograms oats.....	626.46	393.94	3,068.46	184.78	4,561.13	350
	1.5 kilograms oats.....	128.06	-67.50	650.78	67.39	873.08	350
	Per 100 revolutions.....					249.45	

The relative value of the digested matter of hay and of oats for work production in these trials was thus approximately as 5:7.

The digestible nutrients added to the ration by the oats in period VI included no crude fiber, and, as the table shows, 249 grams of these fiber-free nutrients were found equivalent to 100 revolutions of the dynamometer with a draft of 60 kilograms, which is practically equivalent to the 315 grams per 100 revolutions with 76 kilograms draft found in the earlier experiments (p. 57) in which also, as was noted, the additional nutrients were practically fiber-free. Of the digestible nutrients added to the ration in the form of hay in period I-III, on the other hand, over one-fourth consisted of crude fiber, and in this case 353 grams were found to be equivalent to 100 revolutions of the dynamometer. If, however, the digestible crude fiber be omitted in this case, it appears that the fiber-free nutrients of the hay were practically equivalent to those of the oats, 255 grams being required for each 100 revolutions.

As noted previously, Wolff recomputed his experiments on the assumption that the crude fiber was valueless, and obtained results expressed in terms of fiber-free nutrients which were consistent among themselves and agreed with those obtained by Grandean. The following table contains a summary of the results obtained for the maintenance ration expressed both in terms of total nutrients (including digestible crude fiber) and of fiber-free nutrients:

Nutrients for maintenance per 500 kilograms live weight—Wolff.

Experiments.	Including fiber.	Fiber-free.
Experiments of 1881-1885:	Grams.	Grams.
Horse I.....	4,143	3,378
Horse II.....	4,260	3,282
Horse III.....	4,167	3,206
Average.....	4,190	3,322
Experiments of 1885-86—Horse III:		
Period I.....	4,141	3,442
Period II.....	4,194	3,353
Period III and V.....	4,212	3,413
Period VII.....	4,310	3,549
Period VIII.....	4,310	3,490
Period IX.....	[4,586]	3,335
Average.....	4,232	3,430

¹ Omitting period IX.

Nutrients for maintenance per 500 kilograms live weight—Wolff—Continued.

Experiments.	Including fiber.	Fiber-free.
	Grams.	Grams.
Grandeau's experiments:		
Horse II.....	3,636	3,324
Horse III.....	3,617	3,328
Average.....	3,626	3,326
Experiments of 1886-87:		
Period I-III.....	4,202	3,342
Period IV.....	4,150	3,429
Period V.....	3,792	3,329
Period VI.....	3,738	3,364
Average.....	3,971	3,366

The figures inclusive of the crude fiber, as computed by Wolff, evidently correspond approximately with the amounts of metabolizable energy contained in various mixed rations which were sufficient for maintenance. In the earlier experiments, and in those later ones in which approximately equal proportions of hay and grain were consumed, the amount is approximately 4,200 grams per 500 kilograms live weight, which, using Zuntz and Hagemann's factor of 3.96 calories per gram, is equal to 16,632 calories. In the later experiments, in which a larger proportion of grain was fed, the total nutrients required for maintenance ranged from 3,600 to 3,700 grams, equivalent to from 14,257 to 14,652 calories. In other words, the amount of metabolizable energy necessary for maintenance varied with the proportion of coarse fodder present, as would be expected from the results with cattle recorded on previous pages.

The maintenance ration in terms of metabolizable energy, as thus computed, is comparable with that estimated by Zuntz and Hagemann, in the manner explained on pages 55-56, from the total heat production of the animal. That Wolff's results are higher is probably due to the relatively larger proportion of crude fiber in his maintenance rations, since, as shown on page 57, the work is assumed by Wolff's method of calculation to have been done at the expense of the nutrients of the grain, and consequently the remaining portion of the ration, which is regarded as the maintenance portion, was relatively poorer in grain and richer in coarse fodder.

Zuntz and Hagemann¹ attempt to estimate the difference due to the latter fact. They average 31 of Wolff's experiments, divided into two groups, viz, those on light and on heavy work, correcting the actual amount of work done for the loss of live weight and likewise for what they regard as Wolff's error in his estimate of the energy expended in locomotion. They also correct Wolff's estimate

¹ Loc. cit., pp. 420-424; Principles of Animal Nutrition, p. 546.

of the energy of the digested matter by the use of the factor 3.96 calories per gram instead of 4.1 calories per gram. Their comparison of the two groups gives them by difference 31 per cent as the proportion of the available energy of the digested nutrients which was recovered in the form of work, a percentage corresponding very closely to that found for the work of draft in their experiments, viz, 31.4. Upon this basis, they compute in each group the amount of nutrients required for the total work done and by subtraction the total digestible nutrients required for maintenance.

Their results for an animal weighing approximately 500 kilograms are as follows, the equivalent metabolizable energy being obtained by the use of Zuntz and Hagemann's factor of 3.96 calories per gram. The average does not differ materially from that computed directly from Wolff's later experiments.

	Total digestible nutrients.	Equivalent metabolizable energy.
	Grams.	Therms.
Periods of light work.....	3,776	14.95
Periods of heavy work.....	3,763	14.90
Average.....	3,770	14.93

This result they compare with that obtained by them in a balance experiment with a respiration apparatus from which, as noted on page 56, they compute a maintenance ration of 12.93 therms. Their ration, however, contained notably less crude fiber than did Wolff's rations, the differences being as shown in the following table, which includes also the equivalent digestive work, estimated by Zuntz and Hagemann at 2.65 calories per gram:

	Difference in crude fiber fed.	Equivalent digestive work.
	Grams.	Therms.
Periods of light work.....	974	2.58
Periods of heavy work.....	956	2.53
Average.....	965	2.56

Subtracting this amount from the average computed from Wolff's experiments leaves a remainder of 12.37 therms as the metabolizable energy which would have been necessary for maintenance had Wolff's rations contained no more crude fiber than Zuntz and Hagemann's.

Wolff's experiments afford no data for computing in terms of available energy the maintenance requirement in the sense in which this term is used by Zuntz and Hagemann and in the discussion of the maintenance requirements of cattle, on pages 33 to 35, viz, as

equivalent to the necessary demand for internal work. Even if we follow Wolff in regarding the energy of the fiber-free nutrients as an approximate expression of the available energy, his computation of the fiber-free nutrients required for maintenance simply shows the amount of available energy (in this sense) present in a maintenance ration, but gives no indication of how much of this may have been consumed in simple heat production.

MÜNTZ'S EXPERIMENTS.

Müntz,¹ in 1878-79, attempted to determine the maintenance ration of the horse by a different method, viz, by starting with an insufficient ration and gradually increasing it until an equilibrium between food and live weight was secured. His experiments were made upon horses of the Paris Omnibus Co. whose work ration was known from previous experiments. Upon one-third of their regular working ration four horses lost in from one to one and a half months an average of 1.02 pounds per day and head. The ration was then increased to one-half of the work ration. Upon this nine horses, including the four used in the previous experiments, gained on the average 1.08 pounds per day and head. Upon decreasing the ration to five-twelfths of the work ration, six other horses gained 0.46 pound per day and head. The amount of total organic matter consumed by the animals is recorded. Estimating from this the total digestible nutrients and computing the metabolizable energy of the latter at the rate of 3.96 calories per gram, the last two rations afforded the following results:

Metabolizable energy in rations of horses—Müntz.

	Average gain in weight per day.	Average live weight.	Digestible nutrients.	Metabolizable energy.	
				Per head.	Per 1,000 pounds live weight.
One half of work ration.....	Kilos. +0.49	Kilos. 545	Grams. 4,102	Therms. 16.24	Therms. 14.37
Five-twelfths of work ration.....	+0.19	523	3,417	13.53	12.31

GRANDEAU AND LE CLERC'S RESULTS.

Grandeau and Le Clerc,² in addition to the experiments recorded in connection with Wolff's results, fed five cab horses a daily ration of 8 kilograms of hay during a total of 14 periods of a month each (1 to 5 periods for each animal), during each of which the digestibility of the ration was determined. The animals had only a small

¹ Annales de l'Institut National Agronomique, Tome 3, 1878-79.
² L'Alimentation du Cheval de Trait, 1883, III.

amount of walking exercise daily. The following are the results of the several periods:

Metabolizable energy in rations of horses—Grandeau and Le Clerc.

	Total digestible nutrients. ¹	Equivalent metabolizable energy.	Average daily gain or loss of weight.	Average live weight.
Horse 30845 (No. 1):	Grams.	Therms.	Kilos.	Kilos.
January, 1884.....	2,895.3	11.467	-0.19	394.9
April, 1884.....	2,351.9	9.315	+0.47	379.2
August, 1884.....	2,795.5	11.071	+0.03	365.0
September, 1884.....	2,927.8	11.595	² -0.03	366.3
October, 1884.....	2,897.1	11.473	² 0.00	366.0
Average.....	2,773.5	10.983	+0.06	374.3
Horse 29475 (No. 2):				
November, 1883.....	3,041.4	12.045	+0.59	423.6
Horse 29466 (No. 2):				
May, 1884.....	2,470.2	9.784	+0.42	404.0
June, 1884.....	2,909.5	11.523	+0.13	407.1
July, 1884.....	2,692.8	10.663	+0.18	410.6
Average.....	2,690.8	10.656	+0.24	407.2
Horse 29407 (No. 3):				
December, 1883.....	3,062.1	12.128	-0.05	413.9
Horse 26925 (No. 3):				
March, 1884.....	2,726.8	10.799	+0.82	419.0
June, 1884.....	2,644.5	10.473	+0.27	384.3
July, 1884.....	2,719.4	10.770	0.00	387.7
August, 1884.....	2,837.9	11.238	-0.01	388.4
Average.....	2,732.2	10.820	+0.27	394.9

¹ Including fat $\times 2.4$.

² Omitting last day of each month.

On the average of all the periods, the results per day and head were as follows:

Total digestible nutrients (fat $\times 2.4$).....	grams.....	2,783.7
Equivalent metabolizable energy, at 3.96 calories per gram.....	therms.....	11.03
Daily gain in weight.....	kilograms.....	0.19
Average live weight.....	do.....	393.6

The foregoing ration, which was apparently somewhat more than a maintenance ration, is equivalent to 12.12 therms of metabolizable energy per 1,000 pounds live weight. This is materially less than was obtained in Wolff's experiments and about the same as that found by Zuntz and Hagemann for rations containing much grain.

TRUE MAINTENANCE AND LIVE-WEIGHT MAINTENANCE.

The maintenance of an animal in the strict scientific sense signifies the preservation of the store of matter and of potential energy contained in the body, and only a ration which effects this is really a maintenance ration. As has appeared in the foregoing pages, however, much of our recorded information regarding the maintenance

ration is derived from experiments in which the sufficiency of the ration was judged of from its effect in maintaining the live weight of the animal. In experiments on mature animals extending over a considerable period of time, it is unlikely that any gross error is involved, especially if determinations of the nitrogen balance show the protein supply to be adequate. In short periods, on the other hand, and especially in experiments upon young animals, the live weight is a notoriously untrustworthy guide. The general reasons for this are familiar, but in young animals another very important factor enters into consideration. As is well known, the tendency to growth is one of the most marked characteristics of young animals. Waters¹ has shown that this impulse to increase of tissue is so marked that it may apparently take precedence over the demand for maintenance, so that an animal may continue to increase in size of skeleton for a considerable time even on a submaintenance ration.

Some 15 immature cattle were fed for considerable periods on rations just sufficient to maintain their live weight. Under these conditions the animals continued to grow in height, in depth of chest, and length of head. At the same time, however, there was an evident falling off in the amount of fat tissue, both as judged by the eye and as shown by the appearance and by the chemical composition of the carcass. Histological studies, too, showed a reduction in the size of the fat cells, and analysis of the adipose tissue showed a lower fat and higher water and protein content than in check animals. What occurred was evidently a consumption of body fat to supply energy, while at the same time an approximately equal weight of protein tissue was produced which, on account of the relatively low energy value of protein and of the relatively large amount of water accompanying it, represented a much smaller quantity of energy than did the fat tissue which disappeared. In other words, the rations were not really, but only apparently maintenance rations. It is perhaps hardly correct to say that in these experiments growth was maintained at the expense of the fat of the tissues. A more exact statement of the case would be that the increase of protein tissue and water masked the loss of fat. Presumably this effect would be less marked in more mature animals, in which the true maintenance and live-weight maintenance would doubtless approach each other closely when measured over long periods.

FACTORS AFFECTING THE ENERGY REQUIREMENT.

The results of the experiments upon farm animals reported on previous pages render it evident that the actual maintenance requirement, even when computed to a uniform weight or size, is more or

¹ Society for the Promotion of Agricultural Science, Proceedings of 29th Annual Meeting, p. 71.

less variable. For example, in the case of cattle, for which the most extensive and accurate data are available, the range of the energy requirement per day and 1,000 pounds live weight for thin animals in those experiments which are apparently the most accurate is 4.9 to 7.3 therms available energy or 8.5 to 12.8 therms metabolizable energy. Several causes may be responsible for these variations.

MUSCULAR ACTIVITY.

In considering the factors of the fasting katabolism (p. 9), attention was called to the large share which the muscles, and especially the voluntary muscles, have in the heat production of the animal. Even in a state of the most complete rest possible, a very considerable share of the total katabolism takes place in these tissues, due, presumably, to the state of constant slight tension or "tonus" of the living muscle.

MINOR MUSCULAR MOTIONS.

It is rarely the case, however, that an animal, even when at rest in the ordinary sense, does not execute more or less motions of various parts of the body, all of which involve an expenditure of energy, and even apparently insignificant movements may materially increase the amount of metabolism.

Zuntz and Hagemann,¹ for example, report a respiration experiment upon a horse in which the uneasiness caused by the presence of a few flies in the chamber of the apparatus caused an increase of 10 per cent in the metabolism. Johansson² compared the excretion of carbon dioxide by a fasting man when simply lying in bed (awake) with that occurring when all the muscles were as perfectly relaxed as possible. The results per hour were:

Excretion of CO₂ by fasting man.

	Grams.
Lying in bed.....	24.94
Complete muscular relaxation.....	20.72

Benedict and Carpenter³ have compared the metabolism of men during sleep with that of the same subjects lying quietly in bed immediately after waking. In the three cases which they regard as strictly comparable the increase in the heat production during the waking period ranged from 5.8 to 15.2 per cent, averaging 11.4 per cent.

If, then, these comparatively insignificant movements have such a striking effect upon the metabolism, it is evident that the amount of muscular activity must be an important factor in determining the

¹ Landwirtschaftliche Jahrbücher, vol. 23, p. 161.

² Skandinavisches Archiv für Physiologie, vol. 8, p. 85.

³ Carnegie Institution of Washington, Publication 126, p. 241.

relative maintenance requirements of two animals even though their minimum physiological requirements may be identical. In experiments of any considerable duration on normal animals, it is impossible to avoid more or less expenditure of energy in this incidental muscular work, while it is often a matter of difficulty to make the different periods of an experiment comparable in this respect.

LYING AND STANDING.

Furthermore, considerable muscular exertion is involved during the waking hours in maintaining the relative position of the different members of the body. This is notably true of the effort of standing. In experiments by Armsby and Fries¹ the heat radiated per minute by a steer while standing was found largely to exceed that given off while lying, the excess in 25 experiments ranging from 28.3 to 64.5 per cent, although there were indications that the amount of feed consumed was also a factor.

On the other hand Dahm,² working in Zuntz's laboratory and by his methods, found an increase of only 8 per cent in the respiratory excretion of CO₂ by a young bull when standing as compared with that when lying, but Zuntz³ himself in earlier experiments on a dog observed differences similar to those found by Armsby and Fries for cattle, the average oxygen consumption per minute being while lying 174.3 c. c. and while standing 245.6 c. c., or an increase of 41 per cent. Benedict⁴ observed an increase of from 13.3 to 18.8 per cent, or an average of 16.5 per cent, in the heat production of man when standing as compared with that observed when sitting quietly in a chair.

It is clear, then, that of two animals, one of which lies down for 12 hours and the other for 8 hours out of the 24, the former will, other things being equal, require less energy for maintenance. In the results regarding the maintenance ration thus far reported, with the exception of the Pennsylvania experiments, this factor has not been taken into account.

INDIVIDUALITY.

It appears quite probable that those differences between the maintenance requirements of different animals which are ascribed somewhat vaguely to "individuality" are due to a large extent to varying amounts of muscular activity. In general, the nervous, restless animal will have a higher maintenance requirement than the quiet, phlegmatic one. Thus the table on page 40 shows that Armsby and

¹ Bureau of Animal Industry, Bulletins 51, 74, 101, and 128.

² Biochemische Zeitschrift, vol. 28, p. 494.

³ Archiv für die gesamte Physiologie des Menschen und der Thiere (Pfüger), vol. 68, p. 191.

⁴ Loc. cit., p. 244.

Fries's steer A had in every case a materially lower maintenance requirement than steer B, even when the results were corrected to an equal number of hours standing per day. Computed per 1,000 pounds live weight and corrected to 12 hours standing, the results for available energy were as follows:

Available energy required for maintenance—Armsby and Fries.

	Steer A.	Steer B.
	Therms.	Therms.
1905.....	6.23	7.06
1906.....	5.70	6.38
1907.....	4.86	6.50

Steer B was an animal of rather pronounced dairy type and of a nervous disposition, and in all probability his higher maintenance requirement is to be ascribed to this fact. There can be little doubt that temperament is an important factor in determining the maintenance requirement and that there may be a considerable range of individual differences in this respect.

Similarly, any conditions tending to affect the degree of muscular activity will also tend to affect the maintenance requirement. The steer confined in a stall, for example, is likely to take less muscular exercise and therefore to require a smaller amount for maintenance than one simply confined to a pen or an open yard. The animal comfortably bedded and thereby induced to spend much of his time in lying down will consume a smaller portion of his feed for maintenance than one kept under less comfortable conditions. Any sort of excitement is likely to cause increased muscular activity and correspondingly increased consumption of food for maintenance.

CONDITION.

The condition of an animal—that is, the amount of adipose tissue carried—seems to influence the maintenance ration, at least in the case of cattle. This point was first investigated by Kellner.¹ His average result for three fat cattle, as shown in the table on page 43, is considerably higher when computed to the same live weight—that is, per unit of surface—than that for the seven lean animals, viz:

Unfattened--- 10.87 therms metabolizable energy per 1,000 pounds live weight.
Fattened----- 15.05 therms metabolizable energy per 1,000 pounds live weight.

Only one animal, however, was common to the two groups, viz, steer B, the results on which were excluded from the average of the unfattened animals on the ground that it was abnormally high, since the animal never lay down during the experiments. Curiously

¹ Die Landwirtschaftlichen Versuchs-Stationen, vol. 50, p. 245; vol. 53, p. 14.

enough, this animal showed the lowest maintenance ration of the three fattened animals and, moreover, one which is distinctly less per unit of computed surface than in the unfattened state, viz:

Unfattened---- 14.72 therms metabolizable energy per 1,000 pounds live weight.
Fattened----- 13.86 therms metabolizable energy per 1,000 pounds live weight.

No other respiration experiments upon the relative maintenance requirements of fattened and unfattened animals are on record. Evvard's live-weight results, however, as given in the table on page 47, appear to confirm Kellner's conclusion that the relative maintenance ration of fattened animals is greater than that of the same animals unfattened.

One obvious reason why the maintenance requirement should be greater in the former case is the presumably greater muscular effort expended in standing, due to the greater weight to be supported. Zuntz and Hagemann in experiments upon the horse carrying weight on its back found that this increase was proportional to the amount of weight added. The increase indicated by Kellner's averages, however, is greater than would be computed on this assumption, and the same is true of Evvard's fat animals, the difference becoming greater as the animals become fatter.

AGE.

The energy requirement of a young animal is naturally smaller per head than that of an older animal on account of the difference in size. Whether there is any difference in the relative requirements—that is, in the requirement computed to uniform weight or surface—is not altogether clear, few specific results on farm animals being on record. Evvard's results on yearlings, page 46, are somewhat higher than most of the results which have been obtained with mature cattle, although, of course, these figures do not refer to the same individuals at different ages. Armsby and Fries,¹ in a series of respiration calorimeter experiments upon the same two animals in three successive years, observed a progressive decrease in the maintenance requirement of yearlings, 2-year-olds, and 3-year-olds when corrected to a uniform number of hours standing and computed to equal external surface (that is, in proportion to the two-thirds power of the weight).

Somewhat extensive data are on record regarding the metabolism of man at different ages. A summary and discussion of these by Tigerstedt² seem to show clearly that, leaving out of account infants and very aged persons, the metabolism per unit of surface diminishes from youth to maturity. In view of the slow development of man, these results are comparable to such as might be obtained during the first 6 to 12 months of the life of ordinary domestic animals and for

¹ Bureau of Animal Industry, Bulletin 128, p. 55.

² Nagel's Handbuch der Physiologie des Menschen, I, 469.

these ages we have few satisfactory determinations of the maintenance requirement. The results upon swine cited on previous pages seem, it is true, to indicate the contrary relation, viz, a lower relative maintenance requirement for young animals. These results, however, are based upon live-weight experiments and, as already noted, are possibly lower than the true maintenance ration.

If it be true that the maintenance rations of young animals are relatively greater than those of older ones, we may fairly presume it to be due to a considerable extent to the greater amount of muscular activity usually exhibited by young animals.

EXTERNAL TEMPERATURE.

Farm animals belong to that general class known as warm-blooded or homoiothermic animals, whose bodies maintain a nearly constant temperature during health, regardless of that of their surroundings unless the latter be extreme, in which case death soon results.

REGULATION OF BODY TEMPERATURE.

Obviously, the regulating mechanism which maintains a constant temperature in spite of variations in the heat production of the body and in the temperature of its surroundings must be very efficient and very exactly adjusted. The regulation is effected in general in two ways, which may be called, respectively, physical and chemical regulation.

The heat of an animal escapes from the surface of the body chiefly through the skin, but to some extent also through the air passages, being removed both by conduction, by radiation, and by the evaporation of water. A rise of external temperature tends to check the outflow of heat exactly as it would in the case of an inanimate body. This tendency is compensated by a nervous reflex, which allows the capillary blood vessels of the skin to enlarge so that more blood flows through them, thus tending to raise the temperature of the surface and increase the outflow of heat. This phenomenon is readily observed in the flush which follows exposure to high temperatures. This method of regulation is analogous to opening the windows of a room to cool it. If the external temperature continues to rise, perspiration appears, or in the case of animals that have no sweat glands, like the dog, a peculiar form of breathing sets in, and relatively large amounts of water are evaporated from the skin or from the tongue and the interior of the mouth and throat. In this way large quantities of heat are carried off as the latent heat of evaporation of water, somewhat as an overheated room may be cooled by sprinkling the floor. When the external temperature falls again, the process is reversed. Sensible perspiration decreases and the blood is diverted from the capillaries of the skin to the internal capillaries. If this happens too quickly, it

may even lead to congestion of the latter. The process is analogous to the closing of the windows of a room as the weather grows colder.

There is evidently a limit to this method of regulation. If the windows are entirely closed nothing more can be effected in this manner, and if the weather continues to grow colder the fire in the room must be increased. So if the external demand for heat becomes so great as to exceed the limits of adjustment in the body more fuel material is katabolized—that is, more heat is produced. This was first demonstrated by Carl Voit, who obtained the following results for the excretion of carbon dioxide by a man at various temperatures:

Influence of external temperature on metabolism of man—Carl Voit.

Temperature.	Carbon dioxide.	Urinary nitrogen.	Temperature.	Carbon dioxide.	Urinary nitrogen.
° C.	Grams.	Grams.	° C.	Grams.	Grams.
4.4	210.7	4.23	23.7	164.8	3.40
6.5	206.0	4.05	24.2	166.5	3.34
9.0	192.0	4.20	26.7	160.0	3.97
14.3	155.1	3.81	30.0	170.6	-----
16.2	158.3	4.00			

Later and more comprehensive experiments with animals by Rubner have given corresponding results. Thus with two guinea pigs the following figures were obtained in 24-hour experiments:¹

Influence of external temperature on metabolism—Rubner.

Mature animal.			Young animal.		
Temperature of air.	Temperature of animal.	CO ₂ per kilogram and hour.	Temperature of air.	Temperature of animal.	CO ₂ per kilogram and hour.
° C.	° C.	Grams.	° C.	° C.	Grams.
0	37.0	2.905	0	38.7	4.500
11.1	37.2	2.151	10	38.6	3.433
20.8	37.4	1.766	20	38.6	2.283
25.7	37.0	1.540	30	38.7	1.778
30.3	37.7	1.317	35	39.2	2.266
34.9	38.2	1.273			
40.0	39.5	1.454			

A later experiment by Rubner² upon a dog, in which the heat production was measured by a calorimeter, gave the following results:

Temperature of air.	Heat production per kilogram.
° C.	Calories.
7.6	83.5
15.0	63.0
20.0	53.5
25.0	54.2
30.0	56.2

¹ Biologische Gesetze, p. 13.

² Archiv für Hygiene, vol. 11, p. 285.

CRITICAL TEMPERATURE.

It is clear from the foregoing results that when the external temperature falls below a certain limit the heat production of the animal shows a marked increase. This point at which the physical regulation gives way to or begins to be supplemented by the chemical regulation has been called the "critical temperature" for the animal. Above this temperature the radiating capacity of the body surface is varied to meet the varying conditions; below it this method of regulation is largely exhausted, and therefore the heat production is varied to suit the needs. This latter so-called chemical regulation is probably effected largely in the muscles, either by visible motion or by increase in the muscular tonus, either of which involves an increased heat production. This has been clearly shown to be true of man and probably applies also to other animals. Above the critical temperature there appears to be a slight increase in the heat production with rising temperature, probably due to the additional energy required for the various processes of physical regulation.

Any conditions tending to facilitate the escape of heat from the body would obviously act like a fall of temperature. Wind, for example, by removing the layer of partially warmed air next to the skin, tends to remove the heat more rapidly from the body, so that the cold is felt more severely on a windy day, while, on the other hand, the effect of a high temperature is modified by wind. A high percentage humidity of the air on a warm day hinders the removal of heat by evaporation, so that a moist heat is more trying than a dry heat. Cold, moist air, on the other hand, facilitates the escape of heat from the body by increasing the conducting power of the clothing, hair, or fur, so that a damp cold is more severe than a dry cold. The direct rays of the sun may impart a considerable amount of heat to the body, thus moderating the effect of low temperature and, on the other hand, increasing that of high temperature.

FEED CONSUMPTION A SOURCE OF HEAT.

For the sake of simplicity, the foregoing paragraphs have dealt especially with the case of the fasting animal, neglecting one important source of heat, viz, the consumption of feed. As was shown on pages 19–28, the latter results in increasing the katabolism of the body, and whether this be considered the result of the work of digestion or simply designated as specific dynamic effect, the fact is established beyond question. This heat, however, once generated, while unavailable for the physiological processes of the body is just as useful as external heat for keeping it warm. In other words, the consumption of feed will tend to have the same effect as a rise of external tempera-

ture. This being the case, it is clear that at temperatures considerably below the critical temperature, all the metabolizable energy of the feed will be of use to the body. Part of it will be available for physiological uses as already explained, but the remainder, while not available in this sense will nevertheless be of use as a source of heat.

ISODYNAMIC REPLACEMENT.

It was upon his earlier experiments (published in 1883) made under substantially the conditions just indicated that Rubner based his famous law of isodynamic replacement of nutrients which has played a large part in the discussion of nutrition problems. This law may be briefly stated as follows: *In amounts less than a maintenance ration the nutrients replace each other or body tissue in inverse proportion to their metabolizable energy.* The quantities which thus replace each other are accordingly said to be isodynamic. It need scarcely be pointed out that the minimum of protein required for the maintenance of the nitrogenous tissues is not included under this law. Rubner was careful to limit the law to small amounts of food. In his earlier publications he stated that it holds only below the maintenance ration; somewhat later he asserted¹ that it obtains up to an excess of about 50 per cent over the maintenance requirement.

These results of Rubner's have passed into the literature of physiology and are still largely interpreted as representing the relative values of nutrients, while Rubner's factors for the metabolizable energy of nutrients have been extensively used in computing the energy values not only of human dietaries but of stock rations as well. Historically, Rubner's earlier investigations mark an epoch in the science of nutrition. While similar views had previously been advanced by others, Rubner appears to have been the first to investigate the subject experimentally. The conception that the replacement values of the nutrients could be measured by the relative contributions of energy which they make to the activities of the body was a contribution of the first order to the study of nutrition problems, but the exact form given it in these earlier experiments proves to have been but a partial expression of the truth, as Rubner's own later experiment, as well as those of others, have fully demonstrated. (Compare pp. 26-28.)

RELATION OF MAINTENANCE RATION TO CRITICAL TEMPERATURE.

When its surroundings are above the critical temperature, the animal is producing a surplus of heat as a consequence of its necessary physiological activities and disposes of it by the processes of

¹ Biologische Gesetze, p. 20.

physical regulation already described. The heat produced is then in a sense an excretum, and under these conditions obviously the external temperature does not materially affect the maintenance ration. The latter, as already shown, is measured by the amount of available energy necessary to support the vital processes, i. e., by the total fasting katabolism.

Below the critical temperature, however, the conditions are different. At relatively low temperatures all the metabolizable energy of the feed is used directly or indirectly to keep the animal warm, and as the external temperature falls, either more feed must be given or more tissue burned to supply the additional heat required to maintain the body temperature.

FEED CONSUMPTION LOWERS THE CRITICAL TEMPERATURE.

Since feed consumption is itself a source of heat, the animal consuming feed can, other things being equal, withstand a lower temperature than when fasting, and the larger the amount of feed consumed the lower is the corresponding temperature. The matter may also be put in the reverse way. For any particular (low) temperature there is a certain amount of feed the digestion and assimilation of which will yield an amount of heat sufficient to supplement that derived from the fasting katabolism, so as to just maintain the body temperature. This particular external temperature, then, is the critical temperature for that amount and kind of feed, and, conversely, that particular ration may be called the critical amount of feed for the particular external temperature.

CRITICAL TEMPERATURE FOR FARM ANIMALS.

The critical temperature for farm animals has not been definitely determined. In the case of cattle and probably of sheep, however, it is apparently rather low for animals consuming an ordinary ration. Thus Armsby and Fries have found that at about 18° C. the ration of cattle can be reduced considerably below the maintenance requirement without any evidence of increased oxidation of tissue for the sake of heat production. In the case of fattening animals consuming heavy rations and therefore producing a large amount of heat as a result of digestive work, the critical temperature would be still lower and experiments upon such animals have shown that they may be exposed to comparatively low temperatures, as in an open shed or yard; without causing them to oxidize any more food material. As already stated (p. 56) the critical temperature for the horse appears to be relatively higher.

THE PROTEIN REQUIREMENT FOR MAINTENANCE.

PROTEIN KATABOLIZED DURING FASTING.¹

It has already been shown on pages 11-12 that in the previously well-nourished fasting animal the katabolism of protein supplies but a small part of the total energy required for the support of the vital functions. As a preliminary to the consideration of the protein requirement, however, some further consideration of the protein katabolism during fasting is desirable.

INFLUENCE OF PREVIOUS FEED.

The classic experiments of Carl Voit upon fasting dogs showed that while the protein katabolism in the early days of fasting may vary widely according to the previous feed, it soon falls to a comparatively low level which is approximately the same for the individual animal whatever its amount upon the initial days. This behavior is well illustrated by the following results, all upon the same animal, which have been fully confirmed by numerous subsequent experiments.²

Protein katabolism of fasting dog—Voit.

	2,500 grams meat.	1,800 grams meat; 250 grams fat.	1,500 grams meat.	1,500 grams meat.	Bread.
Urinary nitrogen ³ per day:	Grams.	Grams.	Grams.	Grams.	Grams.
Last day of feeding.....	84.4	60.7	51.7	51.7	11.5
First day of fasting.....	28.1	17.5	13.9	12.4	9.1
Second day of fasting.....	11.6	10.9	8.5	8.7	7.3
Third day of fasting.....	8.9	7.8	8.2	7.3	7.0
Fourth day of fasting.....	8.1	6.9	7.0	7.0	6.2
Fifth day of fasting.....	5.7	5.9	6.6	6.9	5.9
Sixth day of fasting.....	6.2	6.0	6.1	6.0	6.1
Seventh day of fasting.....	5.8	5.6	5.6	6.0	.....
Eighth day of fasting.....	4.7	.....	6.0	5.6	.....
Ninth day of fasting.....	.....	.....	.....	5.6	.....
Tenth day of fasting.....	.....	.....	.....	5.3	.....

FASTING KATABOLISM VARIABLE.

It is not true, however, as is sometimes loosely stated, that the protein katabolism of a fasting animal is a constant quantity. On the contrary, in the presence of an adequate amount of body fat, its amount tends to diminish with the progress of fasting. This fact appears more or less clearly in the foregoing experiments, while in later ones it is quite marked. For example, in the experiments by

¹ Compare references on p. 8.

² Zeitschrift für Biologie, vol. 2, p. 307.

³ Computed from Voit's figures for urea. In earlier experiments upon the protein metabolism the urea in the urine, as determined by Liebig's titration method, was commonly taken as the measure of protein katabolism. Later experience has shown that these results are not strictly accurate, but the amount of urea under such circumstances is so nearly proportional to the total urinary nitrogen that the results as given above are entirely adequate as an illustration of the point under discussion.

Benedict, cited on page 15 in illustration of the relative constancy of the energy katabolism, the total protein katabolism showed a distinct falling off, and the same is true in less degree when computed per kilogram weight. The total urinary nitrogen upon the several days of the experiment was:

Protein katabolism of fasting man—Benedict.

Days.	Urinary nitrogen.		Days.	Urinary nitrogen.	
	Total.	Per kilogram weight.		Total.	Per kilogram weight.
	Grams.	Gram.		Grams.	Gram.
1.....	12.24	0.206	5.....	10.87	0.191
2.....	12.45	.211	6.....	10.74	.190
3.....	13.02	.223	7.....	10.13	.181
4.....	11.63	.202			

E. and O. Freund¹ determined the daily nitrogen excretion of Succi, a professional faster, with the following results:

Protein katabolism of fasting man—E. and O. Freund.

Days.	Nitrogen.	Days.	Nitrogen.	Days.	Nitrogen.
	Grams.		Grams.		Grams.
1.....	17.0	8.....	9.74	15.....	5.05
2.....	11.2	9.....	10.05	16.....	4.32
3.....	10.55	10.....	7.12	17.....	5.4
4.....	10.8	11.....	6.23	18.....	3.6
5.....	11.19	12.....	6.84	19.....	5.7
6.....	11.01	13.....	5.14	20.....	3.3
7.....	8.79	14.....	4.66	21.....	2.82

A similar phenomenon was observed by Michaud in experiments on the relative value of proteins described on a subsequent page. A dog, after 44 days abstinence from protein (16 days without food followed by 28 on nonnitrogenous food), excreted daily 1.42 grams nitrogen. The same dog after prolonged feeding upon low protein rations, however, showed in a three-days fast an average daily excretion of only 0.95 grams nitrogen. On the other hand, however, as already pointed out, the fasting protein katabolism may show a very marked increase with the progress of fasting in the absence of a sufficient store of body fat. It appears, then, that in fasting the protein katabolism is much more variable in amount than the total katabolism, and this fact must be remembered in any discussion of the protein requirement.

THE MINIMUM OF PROTEIN.²

It is evident that the comparatively small amount of protein katabolized in the fasting animal so long as its store of fat is reasonably abundant is at least all that is absolutely essential to the vital

¹ Cited by Lusk.

² For a more exhaustive discussion of the subjects of this and succeeding paragraphs, including references to the literature, compare the references on page 8, in particular Magnus-Levy, pp. 198-423; Tigerstedt, pp. 391-480; Lusk, Chapters IV and V.

processes, since the latter go on for a considerable time in a substantially normal manner. The question at once arises whether this fasting katabolism represents the amount of digestible protein which must be supplied in the feed in order to maintain the protein tissues of the body.

INFLUENCE OF NONNITROGENOUS MATERIALS.

In the first place, it is to be remarked that, as just shown, the protein katabolism during fasting is by no means a fixed and definite quantity, but may vary even in the same individual within quite wide limits both absolutely and as regards the proportion of the total energy requirement which is supplied by it. From the results cited on pages 12-13, it is evident that a most important factor influencing the fasting katabolism is the stock of fat in the body and that when the latter is reduced protein is katabolized for the sake of its energy. In other words, a lack of readily available non-nitrogenous material in the body tends to increase the protein katabolism above its minimum value. Evidently, then, in seeking to determine the minimum amount of protein required for maintenance, the food given should contain a liberal supply of non-nitrogenous nutrients to supply the necessary energy for the animal, since otherwise there is danger that the protein will be katabolized for this purpose, resulting in an apparent increase of the maintenance requirement.

RELATION TO FASTING KATABOLISM.

In the early experiments upon this subject, especially those of Voit, the full significance of this fact had not been recognized. His experiments, in which increasing amounts of protein alone were fed (compare p. 79), showed that protein equal to two and a half to three times the fasting katabolism was necessary to reach nitrogen equilibrium, and this result was generalized and passed current for a considerable time.

Munk¹ seems to have been the first to challenge this view and to claim not only that an amount of protein equal to that katabolized during fasting is adequate, but that with an abundant supply of nonnitrogenous material, especially carbohydrates, in the feed a notably smaller amount of protein is sufficient to maintain the nitrogen balance. Munk's experiments either include no comparison with the fasting katabolism of the same animal or a comparison not in all respects satisfactory, but they show clearly that nitrogen equilibrium was maintained on a supply of protein less than that usually found to be katabolized in similar fasting animals.

On the other hand, extensive experiments by Voit and Korkunoff² on dogs led these experimenters to an opposite conclusion. Starting with a ration deficient in protein but containing a very liberal supply of nonnitrogenous nutrients, the protein of the feed was gradually increased until an amount was

¹Virchow's Archiv für Pathologische Anatomie und Physiologie und für Klinische Medizin, vol. 101, p. 91; vol. 133, Supp.; vol. 132, p. 91. Archiv für (Anatomie und) Physiologie, 1896, p. 183.

²Zeitschrift für Biologie, vol. 32, p. 58.

reached sufficient to produce equilibrium between the income and outgo of nitrogen. Two series of experiments were performed, in one of which the non-nitrogenous nutrients consisted chiefly of fat, and another in which they consisted of carbohydrates. Considering only those experiments in which the feed consumed was more than sufficient in amount to supply the estimated demand of the body for energy, it was found that when the nonnitrogenous nutrients consisted of fat the nitrogen (protein) of the feed had to be increased to approximately 130 per cent of the amount katabolized in fasting before nitrogen equilibrium was reached—that is, before the stock of body protein was maintained. When, however, the energy demands of the body were supplied by carbohydrates instead of fats, a supply of nitrogen (protein) in the feed equal to or even somewhat less than the amount katabolized in fasting sufficed to insure nitrogen equilibrium.¹ Cremer and Henderson,² in experiments on a dog with a ration estimated to supply the necessary energy for maintenance, were unable to maintain nitrogen equilibrium on even as small an amount as did Voit and Korkunoff.

In the case of man, on the other hand, numerous experiments seem to have demonstrated that an amount of feed protein notably less than the ordinary fasting katabolism is sufficient to maintain nitrogen equilibrium, although even in this case the comparison in nearly every case is with the average fasting katabolism and not with that of the individual under experiment. This average for man, however, has been well established by numerous experiments and seems not to vary widely for individuals, while in Benedict's experiments³ upon nutrition after fasting a material diminution of the protein katabolism of the subject was observed on the second and third days. In every case the body lost protein, but in experiments 70 and 74 there was a storing up of energy.

Protein katabolism during and after fasting.⁴

	Experiments 69 and 70.	Experiments 71 and 72.	Experiments 73 and 74.	Experiments 75 and 76.
Fasting:	Grams.	Grams.	Grams.	Grams.
First day.....	60.5	35.0	61.7	73.4
Second day.....	85.6	66.2	71.8	74.7
Third day.....	90.2	78.6	69.2	78.1
Fourth day.....	77.8	64.4	62.3	69.8
Fifth day.....			59.9	65.2
Sixth day.....				64.4
Seventh day.....				60.8
Food after fasting:				
First day.....	78.24	63.96	64.44	61.02
Second day.....	59.04		49.50	42.90
Third day.....	60.90		40.68	46.92

Another factor which must be taken into consideration in fixing the minimum of protein is what may be called the time element. Rubner calls attention to the fact that if the protein of the ration is consumed at a single meal there may be for a time a surplus of protein or its digestive products in the system,

¹ Voit and Korkunoff put a different interpretation upon their results, basing it upon the fact that a certain portion of the urinary nitrogen is derived from the nitrogenous extractives of the flesh metabolized in the body. Compare the account of their experiments in the writer's Principles of Animal Nutrition, pp. 135-139.

² Zeitschrift für Biologie, vol. 42, p. 612.

³ Loc. cit., pp. 456 and 529.

⁴ The odd-numbered experiments were the fasting experiments. The even-numbered are those in which food was given and which immediately followed the corresponding fasting experiments.

while at a subsequent period of the day there may be a deficiency which will be made good by a draft upon the proteins of the tissues.

For the purpose of this discussion, it is unnecessary to pursue further the somewhat complicated question of the absolute protein minimum and its relations to the fasting protein katabolism, especially in view of the fact that, as has been shown, the latter is itself more or less variable. It appears well established that on a diet containing an abundance of carbohydrates a supply of protein equivalent to the fasting protein katabolism is sufficient to meet the needs of the organism, while it is possible that a less amount will suffice. Fats appear to be distinctly less efficient than carbohydrates in keeping the protein katabolism at the minimum. Precisely why this is the case has not been fully made out, although Landergren¹ has advanced the explanation that a minimum of carbohydrates is essential to the chemical processes of metabolism and that when a sufficient amount is not supplied in the feed, protein is katabolized for the sake of producing carbohydrates, with the result that on a low protein diet nitrogen katabolism is increased. In any case, it is clear that the protein requirement upon a mixed ration sufficient in quantity is comparatively small.

EFFECT OF SURPLUS OF PROTEIN.

INCREASES PROTEIN KATABOLISM.

But while a relatively small quantity of digestible protein is sufficient, in the presence of an abundant supply of fuel material, to maintain the body in nitrogen equilibrium, an increase of the feed protein above this minimum does not result in any large or long-continued gain of protein tissue by the mature animal, but causes a corresponding increase in the protein katabolism, as is shown by the prompt increase in the amount of nitrogen excreted in the urine.

This fact was demonstrated more than 50 years ago by C. Voit, in collaboration at first with Bischoff² and later alone and with Pettenkofer,³ in experiments on carnivorous animals, and almost innumerable subsequent investigations have shown that it is true not only of these animals, but of man and of herbivorous animals as well. The protein katabolism is determined chiefly by the supply of digestible protein in the feed, and the body comes quite promptly into equilibrium with any amount above the maintenance requirement which can be consumed, the nitrogen of the excreta substantially equaling that of the feed. This is well illustrated by the following selection from Bischoff and Voit's results upon a dog,⁴ arranged in the order of the amount of protein eaten.

¹ Jahresbericht über die Fortschritte der Tier-Chemie, vol. 32, p. 685.

² Gesetze der Ernährung des Fleischfressers, 1860.

³ Published chiefly in the Annalen der Chemie und Pharmacie and the Zeitschrift für Biologie. See also Voit: "Physiologie des Stoffwechsels," in Hermann's Handbuch der Physiologie.

⁴ Voit's compilation, Zeitschrift für Biologie, vol. 3, p. 5.

Daily protein katabolism of dog—Bischoff and Voit.

Dates.	Meat eaten.	Nitrogen of feed. ¹	Nitrogen excreted in urine. ²
	Grams.	Grams.	Grams.
Nov. 26 to 27, 1858.....	176	6.0	12.6
Nov. 24 to 25.....	300	10.2	14.9
May 1 to 4, 1864.....	480	16.3	16.3
Apr. 20 to June 1, 1863.....	500	17.0	18.7
Nov. 22 to 23, 1855.....	600	20.4	22.9
Feb. 13 to 17, 1865.....	800	27.2	26.1
Nov. 20 to 21, 1863.....	900	30.6	31.7
Apr. 14 to 20, 1863.....	1,000	34.0	35.9
Nov. 18 to 19, 1858.....	1,200	40.8	41.1
Apr. 1 to 14, 1863.....	1,500	51.0	49.5
Mar. 25 to Apr. 1, 1859.....	1,800	61.2	59.7
Apr. 5, 1858.....	1,900	64.6	64.9
June 21 to 29, 1863.....	2,000	68.0	67.2
Jan. 22 to 25, 1858.....	2,200	74.8	71.9
Dec. 5 to 7, 1858.....	2,500	85.0	80.7
Jan. 25, 1858.....	2,660	90.4	84.5

Moreover, what has been shown to be true of an exclusively protein diet is substantially true also of one containing liberal amounts of fats or carbohydrates. Thus in the following selection from Bischoff and Voit's experiments¹ bearing upon this point it is clear that, notwithstanding the presence of considerable amounts of fat in the feed, the protein katabolism, as measured by the urinary nitrogen, increased substantially in the same ratio as the protein supply.

Daily protein katabolism of dog—Bischoff and Voit.

Dates (inclusive).	Feed.		Nitrogen of feed. ²	Urinary nitrogen. ³
	Fat.	Lean meat.		
	Grams.	Grams.	Grams.	Grams.
Nov. 22 to Dec. 1, 1857.....	250	150	5.1	7.3
Dec. 2, 1857.....	250	250	8.5	8.9
Dec. 5, 1857, to Jan. 5, 1858.....	250	500	17.0	14.4
Jan. 9 to 11, 1858.....	250	1,000	34.0	28.3
Jan. 15 to 18, 1858.....	250	1,500	51.0	45.9
Apr. 1 to 7, 1859.....	250	1,800	61.2	56.4
Jan. 13 to 14, 1859.....	250	2,000	68.0	63.4

Carnivorous animals have been extensively used in the investigation of such questions as the foregoing, and others which are to be discussed later, largely because with them it is possible to employ a diet consisting of but one or two simple nutrients, but the main facts which have been brought out by such investigations have been shown to be true also of herbivorous animals. In the latter, as in the carnivora, the protein katabolism is determined chiefly by the supply of protein in the feed.

As early as 1852, eight years before the publication of Bischoff and Voit's investigations, Lawes and Gilbert,⁴ in discussing the results of their fattening experiments upon sheep and pigs, called attention to the very wide variations

¹ Gesetze der Ernährung des Fleischfressers, 1860, pp. 97-115.

² Average of nitrogen of lean meat, 3.4 per cent.

³ Computed from urea.

⁴ Report British Association for the Advancement of Science, 1852, Rothamsted Memoirs, Vol. II.

in the amount of protein consumed, both per unit of weight and especially per unit of gain, and concluded that the apparent excess of protein in some cases must have served substantially for respiratory purposes.

Of the numerous later and more specific investigations on herbivora in which the nitrogen excretion has been determined, the following¹ may serve as an example. Two sheep were fed in periods 1 and 7 a basal ration of hay and barley meal. To this ration were added in the intermediate periods varying amounts of nearly pure protein in the form of conglutin (of lupins) or of flesh meal. A comparison of the nitrogen digested from the ration with the urinary nitrogen shows that the latter increased and diminished substantially parallel with the former.

Protein katabolism of sheep per day and head—Henneberg and Pfeiffer.

	Sheep I.		Sheep II.	
	Nitrogen digested.	Nitrogen in urine.	Nitrogen digested.	Nitrogen in urine.
	Grams.	Grams.	Grams.	Grams.
Period 1.....	8.18	7.48	7.81	6.98
Period 2.....	17.86	16.82	17.72	16.37
Period 3.....	27.22	25.75	27.33	23.94
Period 4.....	36.99	32.71	37.07	32.09
Period 5.....	26.76	25.63	26.91	24.54
Period 6.....	17.62	16.64	16.94	15.99
Period 7.....	8.34	8.06	8.00	7.62

UTILIZATION OF PROTEIN LIMITED.

That the mere giving of protein food can not cause a large storing up of protein is indeed sufficiently obvious from daily experience. The muscles of the weakling can not be converted into those of the athlete by feeding him upon a meat diet, nor the small man increased in size by a very abundant protein supply. The protein tissues of the mature animal have reached their natural limit of size and consequently the capacity of the body to store up protein is limited. In such an animal, beyond the minimum required to make good the necessary katabolism in the cells protein can be utilized only to a small extent in the body as protein, and it is therefore rapidly katabolized, its nitrogen appearing in the urine as urea and other familiar end products. Nor is the situation essentially different in the growing or the milk-producing animal. While these animals are able to utilize considerable amounts of feed protein, yet the limit of this utilization is set by the normal rate of growth of the protein tissues or the capacity of the mammary glands to manufacture the casein and other proteins of the milk. Any surplus of protein over the amount which can be used for this purpose is katabolized precisely as is a surplus over the very small demand of the mature animal.

¹ Henneberg and Pfeiffer. *Journal für Landwirtschaft*, vol. 38, p. 215.

As a single striking example there may be cited an experiment by Jordan,¹ in which the protein supply of cows, beginning with a liberal ration, was gradually diminished to about one-half and then gradually increased again to the original amount. The following table shows the average nitrogen balance of cow No. 12 of the second series of experiments, the daily results being grouped into periods as indicated.

Average daily nitrogen balance of cows—Jordan.

Date.	Number of days.	Nitrogen digested.	Nitrogen of milk.	Nitrogen of urine.	Gain by body.
		Grams.	Grams.	Grams.	Grams.
Jan. 30 to Feb. 6.....	7	186.6	81.7	87.0	+17.9
Feb. 6 to 16.....	10	185.2	81.4	87.5	+16.3
Feb. 16 to 26.....	10	161.6	77.5	81.9	+ 2.2
Feb. 26 to Mar. 8.....	10	130.8	74.0	56.5	+ .3
Mar. 8 to 18.....	10	117.2	66.6	43.7	+ 6.9
Mar. 18 to 28.....	10	143.6	69.6	61.8	+12.2
Mar. 28 to Apr. 7.....	10	171.4	71.6	89.2	+10.6
Apr. 7 to 14.....	7	185.7	71.9	104.4	+ 9.4

The amount of milk protein, like the total milk solids, diminished in quite a normal way with the advance in lactation, while the percentage of protein in the solids remained about the same. On the low protein rations of the middle periods there seems to have been some falling off in the amount of milk protein produced (and of the total milk solids as well) in comparison with what might have been expected on an unchanged ration, but the difference is small, except in one or two periods where the protein supply reached the lowest limit. Aside from this the principal effect of the variations in the amount of digestible protein supplied was to increase or diminish the amount of urinary nitrogen, which, as the table clearly shows, rose and fell with the supply of nitrogen in the feed.

PROTEIN AS A SOURCE OF ENERGY.

This increased katabolism of protein, however, is not to be regarded as a total loss of so much food material. The manner in which surplus protein is disposed of is rendered clear by a consideration of the chemistry of protein katabolism. Proteins are resorbed from the digestive tract in the form of comparatively simple cleavage products, chiefly amino-acids, and the body uses these nitrogenous cleavage products as building stones out of which to reconstruct body proteins broken down in the vital processes. As has just been shown, however, this necessary demand is relatively small, while the mature animal has lost the capacity which it had during growth of building up large amounts of new protein tissue. When the blood is, so to speak, flooded with these amino-acids in high protein feeding, some increase in the formation of body protein appears to result, as will be shown immediately, but this consumes a relatively small proportion of the nitrogenous matter and lasts for only a limited time. It is obviously an advantage to the organism, therefore, to be able to dispose of the surplus nitrogen. This it accomplishes by splitting off the NH_2 group and excreting it in the form

¹ New York Agricultural Experiment Station, Bulletins 132 and 197.

of urea, etc., leaving a nonnitrogenous residue which contains the larger portion of the chemical energy of the protein which it represents and is in condition to be oxidized as fuel material. (Compare pp. 30-32.)

The increased nitrogen excretion on a high protein diet is simply the method by which the organism gets rid of useless nitrogen, while retaining the larger share of the energy of the protein for fuel purposes. In other words the organism when confronted with a protein supply in excess of its needs is able by what seems to be a comparatively simple process to transform it into nonnitrogenous fuel material with but slight loss, getting rid of the useless nitrogen as urea through the urine. The increased nitrogen excretion consequent on high protein feeding does not mean the total destruction of the corresponding amount of protein, but simply its transformation into compounds which can serve as sources of energy.

STORAGE OF PROTEIN.

In the mature animal a surplus of feed protein is largely katabolized, so that a continued increase of the protein tissue of the animal can not be brought about, as can that of the adipose tissue, simply by a surplus in the feed. The protein content of such an animal, however, is not to be regarded as absolutely fixed, so that the protein supply has no effect upon it. On the contrary, a considerable range of variation is possible.

When the protein supply is increased, nitrogen equilibrium is not established at once, but for a time more or less storage of nitrogenous material takes place. For instance, when a dog in Voit's experiments¹ was changed from a ration of 500 grams of meat daily for 42 days to one of 1,500 grams, the urinary nitrogen showed the following behavior on the last three days of old feeding and on the first seven of the new:

Storage of protein by dog—Voit.

	Date.	Meat fed.	Nitrogen of feed.	Nitrogen of urine. ²	Gain of nitrogen.
	1863.	Grams.	Grams.	Grams.	Grams.
Experiment No. 40.....	May 29	500	17.0	18.9	-1.9
	May 30	500	17.0	18.2	-1.
	May 31	500	17.0	17.7	-.7
	June 1	1,500	51.0	41.1	+9.9
Experiment No. 41.....	June 2	1,500	51.0	44.1	+6.9
	June 3	1,500	51.0	46.9	+4.1
	June 4	1,500	51.0	48.0	+3.0
	June 5	1,500	51.0	48.6	+2.4
	June 6	1,500	51.0	48.9	+2.1
	June 7	1,500	51.0	50.6	+4.

Upon the lighter ration the animal was losing a small amount of protein daily. On the heavier ration there was a diminishing gain for six days, after

¹ Zeitschrift für Biologie, vol. 3, p. 80.

² Computed from Voit's figures for urea.

proximate equilibrium being reached on the seventh day. The total gain in the seven days was 28.8 grams nitrogen, equivalent to 847 grams of fresh flesh, or about 12 per cent of the surplus fed, equivalent to from 3.5 to 4 per cent of the amount probably present in the body of the 35-kilogram dog.

In order to retain this protein which was stored up in the body, however, it was necessary to continue the heavier ration of 1,500 grams of meat. When, in previous periods of the same series, a ration of 1,500 grams of meat was followed by one of 1,000 grams and this by one of 500 grams, the protein previously stored up was rapidly katabolized again, as the following table shows:

Loss of protein by dog—Voit.

	Date.	Meat fed.	Nitrogen of feed.	Nitrogen of urine. ¹	Gain of nitrogen.
	1863.	Grams.	Grams.	Grams.	Grams.
Experiment No. 38 (last 3 days).....	Apr. 11	1,500	51.0	48.4	+2.6
	Apr. 12	1,500	51.0	50.9	+.1
	Apr. 13	1,500	51.0	52.8	-1.8
	Apr. 14	1,000	34.0	38.6	-4.6
Experiment No. 39.....	Apr. 15	1,000	34.0	36.4	-2.4
	Apr. 16	1,000	34.0	36.4	-2.4
	Apr. 17	1,000	34.0	36.1	-2.1
	Apr. 18	1,000	34.0	34.3	-.3
	Apr. 19	1,000	34.0	35.2	-1.2
	Apr. 20	500	17.0	23.7	-6.7
	Apr. 21	500	17.0	20.4	-3.4
Experiment No. 40.....	Apr. 22	500	17.0	20.9	-3.9
	Apr. 23	500	17.0	18.8	-1.8
	Apr. 24	500	17.0	17.4	-.4
	Apr. 25	500	17.0	18.8	-1.8

The total loss of nitrogen from the body for the 12 days included in the table is 31 grams, or an amount about equal to that stored up in passing from the 500-gram to the 1,500-gram ration.

This comparatively small store of rapidly katabolizable protein in the body after liberal protein feeding Voit designated as circulatory protein, in distinction from the large mass of stable protein which he called organ protein. A variety of other names, corresponding to more or less definite theories as to the nature of the distinction between the two types of protein, have been proposed by later investigators, such as stable and labile, organized and unorganized, tissue and reserve, living and dead, protein. Still others, notably Gruber,¹ explain the temporary storage of nitrogenous matter in the body as due to a lag in the katabolism of protein, so that the splitting off of its nitrogen is not complete within the ordinary 24-hour period. The facts, however, that the nitrogen excretion follows in general the supply in the feed but that a temporary and limited storage of nitrogenous material in the body may result from liberal protein feeding, are undisputed.

FLUCTUATIONS IN BODY PROTEIN.

It is a familiar fact that a fasting animal may live and continue to perform the essential bodily functions for some time, while losing daily a not inconsiderable amount of protein. To cite a single striking example, Rubner observed in a fasting rabbit up to the time of death, on the nineteenth day, a loss of 45.2 per cent of the computed nitrogen of the body.³ While this is an extreme case, neverthe-

¹ Computed from urea.

² Zeitschrift für Biologie, vol. 42, p. 407.

³ E. Voit. Zeitschrift für Biologie, Vol. 41, p. 139.

less it is evident that there must be a relatively large loss of body protein in those more moderate cases in which the deprivation of protein is not continued so long as to cause death. Furthermore, the losses occurring in these latter cases may be made good by subsequent feeding and the animal restored to its original state. Striking examples of the same fact are familiar in the human subject in the emaciation due to long illness and the restoration of the body during convalescence. Pugliese¹ has shown that a similar storage of protein takes place rather rapidly in the liver when a previously fasted animal receives feed again. In brief, it is evident that the body of the mature animal may fluctuate within somewhat wide limits as regards its protein content without necessarily causing any serious or permanent derangement of its functions.

We can hardly suppose such a fluctuation to consist to any large extent of an actual destruction and rebuilding of the cells of muscular or other tissue, but must regard it as effected chiefly by changes in the amount of cell contents—an alternate atrophy and hypertrophy of the cells under the influence of the changing protein supply. This same conception may be invoked, however, to explain small as well as large fluctuations in the body protein. According to Rubner,² the cells of the body seek to maintain an optimum protein content, and in proportion as this becomes reduced they show a capacity for storing up protein, when a more abundant supply is offered in the feed, which is analogous to that observed during growth. On the other hand, when the supply of feed protein is insufficient, protein previously stored may be katabolized.

In other words, as regards its stock of nitrogenous material the organism may exist and function at a higher or lower level according to the amount of protein supplied in the feed, while for each level of protein stock a certain supply in the feed is necessary—that is, the protein required for maintenance varies. With carnivora on a largely protein diet, such as was used in Voit's experiments, the adjustment of the body to the protein supply seems to take place rather promptly. In the case of herbivora, however, the adjustment appears to be more gradual, possibly owing to the relatively large supply of nonnitrogenous ingredients in their feed, and apparently some gain of protein may continue for a considerable time, although when expressed as a percentage of either the total feed protein or of the body protein the gain is relatively small.

RELATION TO ENERGY SUPPLY.

The prime demand of the organism is for energy for the performance of its vital functions, and if necessary it will draw upon its own tissues for this purpose. No clear conception of the laws

¹ Jahresbericht über die Fortschritte der Tier-Chemie, vol. 34, p. 529.

² Das Problem der Lebensdauer, etc.

governing the protein metabolism can be reached without taking into consideration the energy relations.

Ordinarily, the nonnitrogenous nutrients of the feed constitute the principal source of this energy. The proteins, however, or at least the cleavage products of their digestion or transformation, readily undergo a process of deamidization by which their nitrogen is split off and excreted, leaving a nonnitrogenous residue which is available as a source of energy. It is evident, then, that the relative abundance or scarcity of the supply of nonnitrogenous nutrients to the cells of the body may profoundly modify the extent and character of the protein metabolism and consequently the magnitude of the protein requirement.

One instance of this effect is the so-called premortal rise of the protein katabolism of the fasting animal when the store of body fat is reduced below a certain level. (Compare pp. 12-13.) Here the relative deficiency of fuel material in the circulation causes an increased breaking down of the cell protein, presumably by hydrolytic cleavage and subsequent deamidization, its nitrogen being gotten rid of as urea, etc., and the nonnitrogenous residue serving as a source of energy in place of the lacking fat.

A precisely similar thing occurs when the nonnitrogenous nutrients in the feed are relatively deficient and is especially striking in their entire absence. It was pointed out on pages 75-78 that the protein katabolism during fasting is at least an approximate measure of the minimum protein requirement of the body, and that if this amount, or perhaps even less, be supplied in the feed, along with an abundance of nonnitrogenous material, the stock of protein in the body may be maintained. But if the experiment be made of supplying the minimum of protein without nonnitrogenous matter a very different result is obtained.

Thus in one such experiment by E. Voit and Korkunoff,¹ a fasting dog excreted about 4 grams of nitrogen per day, equivalent, of course, to a daily loss of about 24 grams of body protein, while in addition to this it must have been oxidizing considerable body fat. When, however, it was fed slightly more than 24 grams of protein² (4.1 grams nitrogen), with no other feed, its nitrogen excretion jumped to 5.56 grams per day, so that it was still losing daily 1.46 grams of nitrogen, equivalent to 8.76 grams of protein. Instead of the entire amount of protein in the feed being applied to make good the losses of protein tissue, over one-third of it was katabolized, its nitrogen appearing in the urine and its nonnitrogenous residue doubtless being used as fuel material. Protein rather more than equal to the 8.76 grams lost was then added to the ration, but again the protein katabolism increased and the body failed to maintain its stock of protein, and it was not until protein equal to about three times the fasting katabolism was fed that equilibrium was reached. The details of the experiments are shown in the following table,

¹ Zeitschrift für Biologie, vol. 32, p. 67.

² In the form of lean meat from which the extractives had been removed by treatment with water.

the results furnishing also a striking illustration of the interesting relations between protein supply and protein katabolism which had been demonstrated more than 30 years earlier by the classic experiments of Bischoff and Voit.

Effect of protein supply on protein katabolism of dog—E. Voit and Korkunoff.

	Nitrogen in—		
	Food.	Feces and urine.	Gain (+) or loss (—).
	Grams.	Grams.	Grams.
Nothing.....	0	3.996	—3.996
Extracted meat (grams):			
100.....	4.10	5.558	—1.458
140.....	5.74	6.495	— .755
165.....	6.77	7.217	— .447
185.....	7.59	7.804	— .214
200.....	8.20	8.726	— .526
230.....	10.24	10.579	— .339
360.....	11.99	12.052	— .062
410.....	15.58	14.314	+1.266
360.....	13.68	13.622	+ .066

It is clear that in the protein-fed animal, as in the fasting animal, the demands of the organism for energy take precedence over the need for repair material, and that in default of nonnitrogenous material the protein of feed or of tissue is seized upon and katabolized for this purpose even at the expense of a loss of body protein, the body seeming to find it easier to do this than to draw upon the stores of fat in the adipose tissues.

What is so strikingly true in the total absence of nonnitrogenous nutrients holds good also in less degree in case of their relative deficiency. If a portion of the nonnitrogenous nutrients are withdrawn from a mixed ration, the protein katabolism usually increases, while, on the other hand, if nonnitrogenous nutrients be added to such a ration the tendency is to diminish the protein katabolism. This well-known influence of the supply of nonnitrogenous nutrients upon the protein katabolism, even in an abundant ration, is well illustrated by some of Kellner's respiration experiments on cattle,¹ in which starch was added to a basal ration. The following table shows the average daily gain of nitrogen by the animal on the basal ration and the increased gain following the addition of starch.

Effect of nonnitrogenous nutrients on gain of protein by cattle—Kellner.

Animal.	Gain of nitrogen.		
	On basal ration.	With addition of starch.	Difference.
	Grams.	Grams.	Grams.
Ox D.....	12.75	13.71	+ 0.95
Ox F.....	5.64	26.37	+20.73
Ox G.....	— .03	17.09	+17.12
Ox H.....	7.23	12.95	+ 5.72
Ox J.....	5.49	15.05	+ 9.56

¹ Die Landwirtschaftlichen Versuchs-Stationen, Band 53.

It has been shown that this effect is produced not only by the true fats and by the soluble hexose carbohydrates, such as starch and the sugars, but likewise, in the case of herbivorous animals, by those ill-known ingredients of feeding stuffs, especially of the crude fiber and the nitrogen-free extract, which disappear in the passage of the food through the alimentary canal and which are commonly spoken of as being digested. This statement covers also the organic acids, whether resulting from the fermentation of the carbohydrates or contained in the feed.¹

We are not, however, to conceive of a sharp distinction in this respect between an insufficiency and a sufficiency of nonnitrogenous nutrients, but rather of a tendency on the part of the latter to diminish the protein katabolism, a tendency more or less marked according to their abundance in the ration. We are not to understand that no nitrogenous material is katabolized for fuel purposes as long as sufficient nonnitrogenous nutrients are present to supply the demands for energy, nor that even the largest quantities of the latter can prevent the katabolism of protein supplied in excess of the possible constructive use by the body. We may believe that the protein cleavage products, either derived from the feed or from tissue katabolism, are always present in the blood and that more or less deamidization is continually going on, resulting in a use of protein material as fuel. On the other hand, nonnitrogenous substances, derived from the feed or the body fat, are also present and take their share in supplying energy. We may probably conceive of the quantitative character of the katabolism as being determined, in a very broad sense, by the law of mass action. An increase of non-nitrogenous materials in the blood or lymph tends to diminish the deamidization and subsequent oxidation of the cleavage products of protein and through this, secondarily, to diminish the breaking down of body protein or to stimulate and prolong the limited storage of protein possible in the mature animal.

As regards the maintenance requirement, it is evident, then, that the sufficiency of a given amount of protein depends not only upon the plane of protein nutrition of the body, but also upon the amount of nonnitrogenous nutrients supplied with the protein. With an abundant supply of the former an amount of protein equal to the fasting katabolism, or perhaps even less, appears to be a sufficient minimum for maintenance. As the supply of nonnitrogenous materials is reduced a larger supply of feed protein seems to be required to reach equilibrium because more and more of it is diverted for use as fuel, so that in the total absence of nonnitrogenous nutrients a large excess of protein must be fed before equilibrium between income and outgo is reached. In interpreting experiments or formulat-

¹ Compare Armsby, Principles of Animal Nutrition, pp. 117-127.

ing a maintenance ration, therefore, it is not sufficient to consider simply the amount of protein, but account must be taken of the supply of nonnitrogenous materials.

VALUE OF NONPROTEIN.

The crude protein of the feed of farm animals includes not only true protein but a great variety of other nitrogenous substances, grouped for convenience under the designation "Nonprotein." In considering the results of experiments upon the protein requirements of these animals, therefore, it is necessary to determine whether the true protein should be the basis of comparison or whether the nonprotein has some value for maintaining the protein tissues of the body.

The writer has recently¹ considered in some detail the experimental evidence on this point, and the discussion need not be repeated here. It appears to have been demonstrated by recent experimental results, especially by those of Kellner, Morgen, and the Laboratory for Agricultural Research in Copenhagen, that the nonprotein of ordinary feeding stuffs is available for the maintenance of ruminants, probably indirectly through a conversion to protein by means of bacteria in the digestive tract. On the other hand, investigations have not thus far shown that such nonprotein has any material value for production purposes. The writer therefore reached the conclusion that for the present, pending further investigation, it is desirable to consider ordinarily only the digestible true protein in the computation of rations for productive purposes, ignoring the nonprotein. This implies, however, that a discussion of the results of experiments upon the protein requirement shall also be based upon the amounts of true protein supplied and not upon the crude protein. This will have two effects.

First, it will make the protein requirement appear smaller than it really is. Suppose, for example, that a series of trials in which the ratio of digestible nonprotein to digestible protein is 1:10 shows that nitrogen equilibrium is reached with a ration supplying 500 grams protein and 50 grams nonprotein. Regarding the true protein only, the maintenance requirement is 500 grams, while the real requirement of the animal is 550 grams.

In the second place, however, this error will be largely compensated for when the actual computation of rations is also based on the true protein. Thus in the case just supposed, if a maintenance ration be computed from any feed or mixture in which the ratio of nonprotein to protein is the same as in the experiments from which the maintenance requirement was deduced, viz, 1:10, it is obvious that the same final result will be reached whether the maintenance require-

¹ Bureau of Animal Industry, Bulletin 139.

ment be considered to be 500 grams of true protein or 550 grams of crude protein. Only when the proportion of nonprotein to true protein varies widely from that existing in the rations used in determining the protein requirement will any significant error arise in computing rations.

In the results considered on succeeding pages, both the crude protein and true protein of the rations are stated when these are given in the reports of the experiments.

MINIMUM OF PROTEIN FOR FARM ANIMALS.

In considering the protein supply of different species of farm animals, it is important to distinguish between two points of view. On the one hand, it may be sought to determine the least amount of protein upon which the protein tissues of the animal can be maintained. This might be called the physiological minimum. It shows the proportion of protein in a productive ration which is devoted solely to maintenance. On the other hand, the endeavor may be to formulate the most advantageous amount of protein to supply when an animal is actually to be maintained for a time and this amount may very possibly be greater than the physiological minimum. The first point of view, however, is plainly the fundamental one and should receive our first consideration. Having determined the lower limit of protein supply, it will then be possible to consider intelligently the advantages, if any, of a surplus.

CATTLE.

For obvious reasons it is impracticable to ascertain the fasting katabolism of ruminants; their maintenance requirement as regards protein must, therefore, be determined by a process of trial.

The earliest, and for a long time the only, determinations of the maintenance requirements of cattle were those of Henneberg and Stohmann in 1858, the results of which as regards energy were cited on page 39. In 6 experiments the minimum amount of digestible crude protein (total nitrogen $\times$ 6.25) supplied per day was 0.35 pound per 1,000 pounds live weight and this quantity seemed to be more than sufficient for maintenance. On the average of the 6 experiments, in 2 of which there was some loss of body protein, 0.53 pound of digestible crude protein was consumed per 1,000 pounds live weight. Wolff's standard for maintenance, long current, viz, 0.7 pound digestible crude protein, was based on Henneberg and Stohmann's experiments with an allowance for the fact that their experiments were made at a relatively high temperature. Wolff's standard, however, was intended as a guide for actual maintenance feeding rather than as an expression of the minimum protein requirement.

In the light of later experience, the methods of these earlier experiments must be considered imperfect and their results are now chiefly of historical interest. The first experiments by modern methods were those of G. Kühn and

Kellner at the Moeckern Experiment Station,¹ which include determinations of the gain or loss of fat as well as of protein and hence afford a secure basis for judgment as to the sufficiency of the energy supply. Including subsequent slight corrections by Kellner,² the principal results as regards protein are summarized in the following table:

Gain or loss of protein by cattle—G. Kühn and Kellner.

No. of animal.	Live weight.	Protein per day and 1,000 pounds live weight.			
		Digestible in feed.		Gain by animal.	
		Crude protein. ³	True protein. ⁴	Protein.	Fat.
	Pounds.	Pound.	Pound.	Grams.	Grams.
II.....	1,394	0.65	0.58	-17.2	+ 75.8
III.....	1,393	.53	.35	-24.5	+ 63.0
IV.....	1,386	.53	.34	-25.9	+ 20.4
V.....	1,327	.75	.60	+21.8	+106.6
VI.....	1,420	.71	.57	+11.8	+119.3
XX.....	1,481	.80	.65	- 3.2	+ 71.7
A.....	1,365	.71	.56	+27.2	+103.0
B.....	1,348	.35	.28	-65.3	- 78.0

If the very small loss of protein by ox XX may be regarded as falling within the limits of experimental error, the eight experiments may be averaged as follows:

Animal.	Digestible in feed.		Gain by animal.	
	Crude protein.	True protein.	Protein.	Fat.
	Pound.	Pound.	Grams.	Grams.
Animals V, VI, XX, and A	0.74	0.60	14.4	+100.2
Animal II.....	.65	.58	-17.2	+ 75.8
Animals III, IV, and B.....	.47	.32	-38.6	+ 5.4

It appears that approximately 0.6 pound of digestible true protein or 0.74 pound of crude protein per 1,000 pounds live weight was at least sufficient to rather more than maintain nitrogen equilibrium when the total energy supply in the ration was sufficient to cause a small gain of fat, while half this amount of true protein or 0.47 pound of crude protein was manifestly insufficient. A reduction to 0.35 pound digestible true protein or 0.53 pound digestible crude protein in the cases of ox III and ox IV, even with a sufficient supply of non-nitrogenous material to cause some gain of fat, resulted in a loss of protein from the body, while in the case of ox B, with a slightly lower supply of true protein and a materially lower one of crude protein and a ration materially below the maintenance requirement, the loss of protein was still greater. The considerable loss of protein by ox II is not readily explicable.

Experiments upon the same subject were also made by the writer⁵ in 1892-1898, chiefly upon rations of timothy or mixed hay, with the addition in Experiment VII of starch, but also, in Experiment VIII, upon a ration consisting

¹ Die Landwirtschaftlichen Versuchs-Stationen, vol. 44, p. 257; vol. 47, p. 275.

² Die Ernährung der Landwirtschaftliche Nutztiere, 5th ed., p. 411.

³ Corrected for estimated loss of nitrogen in drying of feces.

⁴ As reported in the original account of these experiments.

⁵ Pennsylvania Experiment Station, Bulletin 42, p. 165.

chiefly of grain together with a minimum of wheat straw. The results of these experiments are contained in the following table:

Nitrogen balance per 1,000 pounds live weight—Armsby.

Experiment.	Digestible in feed.		Nutritive ratio 1:	Gain or loss of nitrogen by body.
	Crude protein.	True protein.		
	Pound.	Pound.		Grams.
Experiment I:				
Steer 1.....	0.30	0.26	20.1	-2.7
Steer 2.....	.27	.23	20.4	- .4
Steer 3.....	.31	.27	18.6	-1.2
Experiment II:				
Steer 1.....	.45	.38	13.4	+1.9
Steer 2.....	.47	.40	13.6	+4.2
Steer 3.....	.49	.42	12.8	+5.2
Experiment VI:				
Steer 1.....	.62	.59	10.9	+4.7
Steer 2.....	.60	.55	10.9	+6.0
Steer 3.....	.67	.63	10.6	+2.8
Experiment VII:				
Steer 1.....	.49	.31	23.0	+5.7
Steer 2.....	.44	.26	25.3	+3.7
Steer 3.....	.51	.30	23.9	+4.4
Experiment VIII:				
Steer 1.....	.62	.52	10.4	+ .2
Steer 2.....	.57	.48	10.7	- .1
Steer 3.....	.66	.55	10.6	-2.0

In Experiments II, VI, VII, and VIII digestible crude protein ranging from 0.44 to 0.67 pound fully sufficed for maintenance, with a single exception. The range of true protein was somewhat wider, viz, 0.26 to 0.63 pound. The rations of Experiment VII were relatively richer in nonprotein than were those of the other experiments, and the adequacy of these very low protein rations suggests a utilization of the nonprotein, although the abundance of nonnitrogenous nutrients, as shown by the nutritive ratio, may also be a factor. The rations of Experiment I were obviously inadequate, even although the supply of non-nitrogenous matter was liberal.

Experiments upon a steer by Armsby and Fries¹ in which the respiratory products were determined gave results in general accord with those already cited. Computed per 1,000 pounds live weight, these results were as follows:

Nitrogen balance per 1,000 pounds live weight—Armsby and Fries.

	Digestible.		Gain or loss by body.	
	Crude protein.	True protein.	Nitrogen.	Fat.
	Pound.	Pound.	Grams.	Grams.
1902.				
Period A.....	0.45	0.36	- 9.1	-286.5
Period B.....	.52	.42	- 1.3	- 89.2
Period C.....	.53	.44	- .4	+ .6
Period D.....	.68	.55	+12.3	+ 16.8
1903.				
Period I.....	.66	.46	-16.4	-192.9
Period II.....	.51	.38	-15.0	-350.8
Period III.....	.70	.53	- 2.3	-169.7
Period IV.....	.97	.84	+ 9.2	+196.4
1904.				
Period I.....	.44	.34	- 9.5	-312.7
Period II.....	.74	.55	- .8	- 75.2
Period III.....	.60	.46	- .5	-155.4

¹ Bureau of Animal Industry, Bulletins 51, 74, and 101.

In periods C and D of 1902 and period IV of 1903, the only ones in which maintenance was reached, the crude protein ranged from 0.53 to 0.97 and the true protein from 0.44 to 0.84. In a later series of experiments¹ on two immature steers, from 0.92 to 1.13 pounds of crude protein, or 0.69 to 0.77 pound true protein per 1,000 pounds live weight sufficed for maintenance in three periods in which there was some gain of fat. The experiments furnished no evidence that so large an amount was necessary, since the next lowest amount was 0.44 pound crude protein or 0.37 pound true protein in a ration producing a slight gain of fat but a small loss of protein.

The investigations of the Laboratory for Agricultural Research in Copenhagen upon the protein requirements for milk production include also two experiments on dry cows² with rations furnishing relatively small amounts of digestible nitrogenous matter, chiefly in the form of true protein. The periods in which an approximate nitrogen balance was secured gave the following data:

Nitrogen balance of dry cows per day and head—Copenhagen experiments.

Cow and period.	Live weight.	Crude protein (N. $\times$ 6.25) digested.		Gain of nitrogen per head by animal.
		Per head.	Per 1,000 pounds live weight.	
Cow 117:				
Period 2.....	488	Grams. 87.5	Pound. 0.18	Grams. -3
Period 4.....	485	100.0	.21	+2
Cow 134:				
Period 1.....	466	143.8	.31	-5
Period 4.....	443	112.5	.25	+3

The experiments on milking cows also afford approximate data as to the maintenance requirement. If the protein of the milk is subtracted from the total digestible protein of the feed, the remainder is obviously the maximum amount which was available for maintenance. In Bulletin 139 of this bureau, pages 38-39, there are given the results of those experiments in which the smallest amounts of protein were consumed. Selecting from among these those in which there was an approximate nitrogen equilibrium, we obtain the results tabulated below:

Daily gain or loss of protein by cows—Copenhagen experiments.

Cow and period.	Live weight.	Crude protein digested.	Protein of milk.	Maximum crude protein available for maintenance.	Gain of protein by animal.
Sixtieth report:	Kilos.	Grams.	Grams.	Grams.	Grams.
Cow No. 10, period 6.....	446	600.0	387.5	212.5	-12.5
Cow No. 53, period 4.....	454	543.8	350.0	193.8	-12.5
Cow No. 53, period 6.....	451	568.8	306.3	262.5	+18.8
Cow No. 68, period 4.....	461	575.0	393.8	181.2	-31.3
Cow No. 68, period 14.....	441	506.3	312.5	193.8	-12.5
Cow No. 58, period 4.....	485	531.3	325.0	206.3	-6.3
Cow No. 58, period 6.....	485	581.3	293.8	287.5	+37.5
Sixty-third report:					
Cow No. 68, period 6.....	453	575.0	368.7	206.3	-25.0

¹ Bureau of Animal Industry, Bulletin 128.

² Sixty-third Report, pp. 28 and 30.

In the two periods in which there was a gain of protein by the animal the crude protein available for maintenance, computed per 1,000 pounds live weight, was:

	Pound.
Cow No. 53, period 6.....	0.58
Cow No. 58, period 6.....	.59

In the four periods in which the loss of protein by the animal did not exceed 12.5 grams (2 grams nitrogen) the corresponding amounts were:

	Pound.
Cow No. 10, period 6.....	0.48
Cow No. 53, period 4.....	.43
Cow No. 68, period 14.....	.44
Cow No. 58, period 4.....	.43

These results are quite of the same order as those obtained by Kellner and by Armsby, while those on the two dry cows are much lower, with the exception of a single result of Armsby's. (Experiment I, steer 2.)

In drawing conclusions from the results recorded in the foregoing pages, it is important to remember that what it is sought to determine is the minimum protein requirement. As has been shown on previous pages, an excess of feed protein above this minimum is, in the case of the mature animal, substantially all katabolized, producing no material gain of protein. The fact of an equality of income and outgo of nitrogen upon a given ration of protein, therefore, while it shows that the quantity consumed is sufficient for maintenance does not show that a smaller amount would not suffice. What we have to consider is the evidence of the experiments regarding the least amount sufficient for maintenance. It is evident that this minimum amount is relatively small, but it is also evident that the recorded results do not suffice to fix with certainty the absolute minimum.

The lowest recorded amounts per 1,000 pounds live weight upon which nitrogen equilibrium was reached were 0.21 pound and 0.25 pound of crude protein in the Copenhagen experiments on dry cows, while almost as small a quantity, viz, 0.27 pound crude protein or 0.23 pound true protein in Armsby's Experiment I, steer 2, fell very little short of reaching nitrogen equilibrium. Aside from these somewhat exceptional results, the lowest figures obtained per 1,000 pounds live weight were 0.43 pound crude protein and 0.38 pound true protein. The maximum is found in Armsby and Fries' experiment of 1903-4, viz, 0.96 pound crude protein and 0.84 pound true protein, but it seems altogether probable that the animal in this period was consuming a surplus of protein. If we omit these few extreme results in either direction, the average and range of the results of the other experiments are as follows:

Average and range of protein requirements of cattle.

	Number of experiments.	Protein requirement.		
		Average.	Maximum.	Minimum.
Crude protein.....	19	Pound. 0.55	Pound. 0.75	Pound. 0.43
True protein.....	12	.52	.63	.38

It seems safe, therefore, to estimate 0.6 pound of crude protein or 0.5 pound true protein per 1,000 pounds live weight as representing in a general way the minimum protein requirement of mature cattle with a probable range of 0.1 or 0.2 pound either way under varying conditions.

For actual maintenance feeding it is probable that a somewhat more liberal supply of protein than is indicated by these figures would be advisable. Rations so poor in protein, if containing an adequate amount of nonnitrogenous matter, would probably suffer a loss through failure of the animal fully to digest the nonnitrogenous matter. A somewhat narrower nutritive ratio could readily be reached in practice in ordinary feeding without additional expense and from the standpoint of digestibility would very likely be justified.

SHEEP.

While a considerable number of experiments with sheep are on record in which approximate maintenance as a whole was observed, at least so far as could be judged from the live weight, few of them afford satisfactory data as to the minimum protein requirement. For the immediate purpose of this discussion, only experiments in which the nitrogen balance was actually determined are available, mere maintenance of weight being too uncertain a criterion.

A distinct difference between cattle and sheep, which affects the protein requirement, lies in the greater demand for protein incident to the growth of wool in the latter animals as compared with that of hair in the former. The results of determinations by Armsby and Fries¹ on the same two steers in two consecutive winters showed an average production of epidermal tissue, including the growth of hair and the loss in brushings, equivalent to 0.19 gram nitrogen per day and 1,000 pounds live weight, which is equal to 0.0025 pound protein, an amount too small to materially affect our estimates of the maintenance requirement. In the case of sheep, determinations of the growth of wool by several investigators afford the following data regarding the average amount of protein required for this purpose. The results have been computed per 1,000 pounds live weight for the sake of ready comparison:

Protein contained in daily growth of wool per 1,000 pounds live weight.

	Pound.
Henneberg, Kern, and Wattenberg ² —Mature sheep.....	0.132
Henneberg, Kern, and Wattenberg ³ —Lambs.....	.143
Weiske ⁴ —Growing sheep.....	.100
Henneberg and Pfeiffer ⁵ —Mature sheep.....	.149
Pfeiffer and Kalb ⁶ —Mature sheep.....	.150
Average	.135

Although, as the foregoing figures show, the protein requirements of sheep for the growth of wool are considerably greater than those of cattle for the

¹ Bureau of Animal Industry, Bulletin 128.

² Journal für Landwirtschaft, vol. 26, p. 549.

³ Ibid., vol. 28, p. 289.

⁴ Landwirtschaftliche Jahrbücher, vol. 9, p. 205.

⁵ Journal für Landwirtschaft, vol. 38, p. 215.

⁶ Landwirtschaftliche Jahrbücher, vol. 21, p. 175.

growth of hair, the absolute difference, after all, does not add very greatly to the total maintenance requirement.

In Henneberg and Stohmann's Weende experiments¹ upon two sheep fed exclusively on meadow hay, there was digested on the average per 1,000 pounds live weight:

	Pounds.
Crude protein (total N × 6.25).....	1.32 ²
Nitrogen-free extract.....	6.28
Crude fiber.....	3.93
Ether extract.....	.32

and the animal gained 0.17 pound of body protein, in addition to that stored in the wool, and a small amount of body fat.

In a series of 20 digestion and metabolism experiments by Schulze and Märcker,³ decidedly smaller amounts of protein proved sufficient to maintain nitrogen equilibrium. In one case on a ration containing as little as 0.335 pound digestible crude protein per 1,000 pounds live weight, but having a very wide nutritive ratio (1:17.2) there was a slight gain of total protein, but one less than the amount required for the growth of wool. If we exclude this experiment and also 4 experiments in which it is evident that an excess of protein was fed, we have as the average of 6 experiments in which no loss of body protein was observed 0.653 pound digestible crude protein per 1,000 pounds live weight, while in two other experiments in which the minimum losses of 0.005 and 0.015 pound body protein were observed, the protein supply was, respectively, 0.655 and 0.690 pound. It is evident, then, that the protein supply of the sheep can be materially reduced below the amount fed in Henneberg and Stohmann's experiments without leading to a loss of body protein.

That such is the case seems to be clearly shown by the recent investigations of Katayama at the Moeckern Experiment Station,⁴ in which increasing amounts of nearly pure protein ("aleuronat") were added to a basal ration very poor in protein, consisting of hay, oat straw, starch, and cane sugar. The protein in every case was substituted for a corresponding amount of starch, so that the total energy of the ration remained substantially unchanged. In the third period of the experiment both of the two sheep showed some loss of body protein, while in the fourth period, with more protein in the food, a gain was noted. In neither case was the growth of wool taken into consideration. By adding in the one case the loss of body protein to the digestible protein of the food and in the other period subtracting the gain, the author gets the following comparison:

Protein requirement of sheep per day and head—Katayama.

	Sheep I (weight, 34 kilograms).	Sheep II (weight, 38 kilograms).
	Grams.	Grams.
Period III:		
Nitrogen digested.....	1.978	2.412
Loss of body protein.....	.079	.216
	2.057	2.628
Period IV:		
Nitrogen digested.....	3.176	3.360
Gain of body nitrogen.....	1.107	.515
	2.069	2.845
Average for maintenance.....	2.063	2.737
Maintenance per 1,000 pounds live weight:		
Nitrogen.....	.061	.072
Protein.....	.379	.450

¹ Neue Beiträge, etc.

² Estimated by Kellner to contain 1.04 pounds of true protein.

³ Wolff: Die Ernährung der Landwirtschaftlichen Nutztiere, p. 300.

⁴ Die Landwirtschaftlichen Versuch-Stationen, vol. 69, p. 321.

On the average of the two animals, 0.41 pound digestible crude protein per 1,000 pounds live weight was apparently sufficient to prevent a loss of nitrogen from the body. The crude protein in this case was practically all true protein, only minimum amounts of nonprotein being present in the ration. Since, however, the growth of wool must have gone on, with a corresponding storage of nitrogen, this apparent maintenance ration would really result in a loss of protein by the active tissues of the body.

If we add to Katayama's average 0.14 pound per 1,000 pounds live weight for the growth of wool, we get 0.55 pound as representing the minimum protein requirement for the maintenance of mature sheep, including the growth of wool. It is interesting to note that, according to these figures, the actual maintenance requirement for the body tissues is quite as low relatively as for cattle.

It is true that some earlier experiments seem to indicate a greater demand for protein than the foregoing figures show. Thus, in the experiments cited on page 80 to illustrate the influence of the protein supply upon its katabolism, a ration containing about 2.5 pounds digestible protein per 1,000 pounds live weight seemed to be about sufficient for maintenance, including the wool production, while a ration containing 2.27 pounds showed a loss of protein. Similarly, in earlier experiments by Henneberg, Fleischer, and Müller,¹ a ration containing 1.25 pounds digestible crude protein following one supplying 6.51 pounds resulted in a loss of protein by the animal. Notwithstanding these isolated results, however, it seems justifiable to accept the lower figure obtained by Katayama as representing approximately the minimum protein requirement of mature sheep.

SWINE.

The only data available as to the minimum protein requirement of swine are derived from the two experiments upon fasting animals by Meissl, Strohmer, and Lorenz (referred to on p. 51). The animals were Yorkshire swine, one 14 months old and weighing 140 kilograms, and the second, whose age is not given, weighing 120 kilograms. In the fasting state the nitrogen excretion of these animals was as follows:

	Live weight.	Nitrogen excretion.
Animal I:		
Average of first, second, and third days' fasting.....	Kilos. 140	Grams. 9.80
Animal II:		
Average of third, fourth, and fifth days' fasting.....	120	6.77

The nitrogen excretion was equivalent, respectively, to 0.44 and 0.35 pound of protein per 1,000 pounds live weight, or about the amounts which appear to be required for cattle and sheep. No

¹ Jahresbericht der Agriculturchemie, vols. 16-17, II, p. 145.

experiments are on record which demonstrate the sufficiency of this amount as a maintenance ration.

THE HORSE.

In the experiments by Grandeau and Le Clerc described on pages 62-63 the nitrogen balance of the horses was determined during 6 of the periods. The following table shows the amounts of protein and of nonprotein nitrogen digested in each period, the urinary nitrogen, and the small losses in epithelial tissue (epidermis, hoofs, hair, etc.):

Nitrogen balance of horses—Grandeau and Le Clerc.

	Horse No. 1.		Horse No. 2.		Horse No. 3.	
	January, 1884.	April, 1884.	November, 1883.	May, 1884.	December, 1883.	March, 1884.
Digested:						
Protein nitrogen.....	Grams. 43.19	Grams. 34.29	Grams. 38.94	Grams. 34.22	Grams. 41.82	Grams. 24.72
Nonprotein nitrogen.....	1.20	— 1.01	— 3.23	10.78	— 2.09	— 4.58
Total nitrogen.....	44.39	33.28	35.71	35.00	39.73	20.14
Nitrogen of epithelial tissue...	1.46	1.46	1.46	1.46	1.46	1.46
Urinary nitrogen.....	35.17	38.75	30.70	41.92	37.62	32.70
Nitrogen gained.....	7.76	— 6.93	3.55	1.62	.65	—14.02

Omitting the results upon horse No. 3 in March, when the digestible protein was exceptionally low, the other five periods show an average daily gain of nitrogen of 1.33 grams, while the average crude protein digested (total N. $\times$ 6.25) was 235 grams, equivalent to 0.59 pound per 1,000 pounds live weight.

THE OPTIMUM OF PROTEIN.

The data of the foregoing paragraphs seem to indicate a striking uniformity in the minimum protein requirement of the principal species of domestic animals when mature, 0.4 to 0.6 pound per 1,000 pounds live weight apparently sufficing to maintain nitrogen equilibrium under favorable conditions.

It should be clearly understood, however, that this figure represents a more or less accurately determined limit. It purports to be the amount below which the protein supply can not be reduced without eventual protein starvation. The animal body, however, may adjust itself to a wide range of protein supply above the minimum, using some of it to increase the stock of protein in the body and katabolizing the remainder as fuel material. An increase in the protein supply above the minimum results, after a relatively short time, in the maintenance of the body protein at a higher level. The practical question in actual maintenance is far less in regard to the

least amount of protein which may be used than as to the most advantageous level of protein nutrition; that is, as to the optimum of protein.

This question has been warmly debated in connection with human nutrition.

Numerous recent investigations, notably those by Chittenden and his associates,¹ have shown that the protein of human dietaries can be reduced much below the amount previously regarded as necessary. In most cases there is no possibility of a direct comparison with the fasting katabolism of the same individual, but as previously stated (p. 77) a considerable number of instances are on record in which the nitrogen supply has been reduced to an amount materially lower than that usually found for the fasting protein katabolism of individuals of the same weight without leading to a loss of protein from the body. In all these experiments, the nonnitrogenous nutrients consisted, as is usually the case in human dietaries, to a considerable extent of carbohydrates.

Moreover, while some of the earlier experiments were for short periods and on comparatively few individuals, Chittenden's investigations covered long periods and were made on 26 different individuals, including 5 professional men under observation for 8 months, 13 soldiers observed for 6 months, and 8 trained athletes under observation for 5 months. His results clearly demonstrate the possibility of maintaining the body protein and fully preserving the health and vigor upon a low protein diet. In other words, a relatively low level of protein nutrition for several months is not inconsistent with health and efficiency.

In some of the earlier experiments in which very low protein diets were fed to dogs, the health of the animals suffered seriously and there has been a tendency to ascribe these ill effects to the continued use of very small amounts of protein. Later investigations by Chittenden, however, in which dogs were kept on a low protein diet for the greater part of a year, seem to have demonstrated that the ill effects observed in the earlier experiments were due to unhygienic conditions and not to the low protein diet. It may be remarked that in experiments upon cattle, rations very low in protein have been fed for a considerable time without any perceptible deleterious effects. No similar determinations upon other species of farm animals appear to have been made.

On the whole, then, it can not be said that a considerable surplus of protein over the minimum requirement for maintenance—that is, the maintenance of protein nutrition on a high plane—has been proved to be of any material advantage in the maintenance either of men or domestic animals during periods covering several months. Whether a continued low protein diet through years or generations would show a different result is at present largely a matter of speculation. It is to be remarked, however, that the particular point under discussion is the protein requirement of the mature organism. That a deficiency of protein in the diet of a growing animal may have disastrous results is clear. If, however, the habitual food supply of a race of men or a group of animals is low in protein, the young are likely to share this deficiency with the mature, and it seems not

¹ *Physiological Economy in Nutrition*. Stokes Co., 1907.

impossible that this is an important factor in the alleged physical inferiority of certain races of men living on a low protein diet. This consideration warns us to exercise care in this respect in the management of the breeding herd.

In the actual maintenance feeding of farm animals, the matter of the digestibility of the ration must also be considered. It has been shown that a relative deficiency of protein in the ration tends to depress the apparent digestibility of both the protein and nonnitrogenous nutrients, especially in the case of ruminants. A maintenance ration for these animals containing the minimum amount of protein, together with the quantities of nonnitrogenous nutrients required to maintain the energy supply, would have a nutritive ratio, computed in the ordinary way, of approximately 1:12. On such a ration, there would, in all probability, be some loss of digestibility. An increase of its protein by 50 per cent would very probably effect a gain in digestibility which would more than offset the increased cost, if any. Indeed, unless feeds especially poor in protein are used, it may often be difficult, even if desirable, to reduce the protein content of a maintenance ration to the low level of absolute necessity.

RELATIVE VALUES OF PROTEINS.

In the discussions of the foregoing paragraphs, following the usual practice, the word protein has been used as if it designated a single chemical individual. In reality, of course, this is very far from being the case. The protein of the body or of the feed in this conventional sense includes a large number of distinct and in some respects, widely differing proteins. The studies of the chemical structure of the protein molecule made in recent years, beginning with the fundamental investigations of Emil Fischer, have shown marked differences in the proportions of the various "building stones" (amino acids, etc.) contained in different proteins, while studies in immunity have led to the recognition of marked specific and individual biological differences in animal proteins, although these have not been definitely correlated with differences of chemical constitution. It is pertinent to inquire, therefore, whether we are justified in discussing the nutritive functions of feed protein as a group or whether we must consider each individual protein by itself. In other words, are there recognizable differences in nutritive value between individual proteins?

DIFFERENCES IN CONSTITUTION OF PROTEINS.

In discussions of this question, the chief emphasis has been laid upon the demonstrated differences in the proportions of the various cleavage products yielded by the different proteins when subjected

to acid hydrolysis. The following table shows some of the more recent results obtained by Abderhalden and by Osborne:

Constituents of proteins—Abderhalden and Osborne.

Constituents.	Gliadin of wheat. ¹	Glutenin of wheat. ¹	Zein of maize. ¹	Phaeolin of white bean. ¹	Casein. ²	Egg albumin. ²	Serum albumin of horse blood. ²	Serum globulin of horse blood. ²	Ox muscle. ³	Edestin from hemp. ⁴
	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.
Glycocol.....		0.89		0.55	0.00	0.00	0.0	3.5	2.06	3.80
Alanin.....	2.00	4.65		1.80	.90	2.10	2.7	2.2	3.72	3.60
Amino-valerianic acid.....	.21	.24		1.04	1.00			(⁵)	.81	(⁵)
Leucin.....	5.61	5.95		9.56	10.50	6.10	20.0	18.7	11.65	20.90
Prolin.....	7.06	4.23		2.77	3.10	2.25	1.0	2.8	5.82	61.70
Phenylalanin.....	2.35	1.97		3.25	3.20	4.40	3.1	3.8	3.15	2.40
Aspartic acid.....	.58	.91		5.24	1.20	1.50	3.1	2.5	4.51	4.50
Glutamic acid.....	37.33	23.42	16.87	14.54	11.00	9.10	7.7	8.5	15.49	76.30
Serin.....	.13	.74		.38	.23		.6		(?)	.33
Tyrosin.....	1.20	4.25		2.17	4.50	1.10	2.1	2.5	2.20	2.10
Cystin.....	.45	.02			.06	.20	2.3	.7		.25
Lysin.....	.00	1.92	.00	3.59	5.80				7.59	1.00
Histidin.....	.61	1.76	.81	1.97	2.59				1.76	1.10
Arginin.....	3.16	4.72	1.82	4.72	4.84				7.47	11.70
Ammonia.....	5.11	4.01	3.61	2.06	1.95	1.63			1.07	
Tryptophan.....	(⁵)	(⁵)	.00	(⁵)	1.50	(⁵)	(⁵)	(⁵)	(⁵)	(⁵)
Total.....	65.81	59.66	23.11	53.64	52.37	28.38	42.6	45.2	67.30	

¹ Osborne. The proteins of the wheat kernel, pp. 110, 113, and 118.

² Abderhalden. Lehrbuch der physiologischen Chemie.

³ Osborne. The American Journal of Physiology, vol. 24, p. 437.

⁴ Abderhalden. Loc. cit.

⁵ Present.

⁶ A prolidin.

⁷ A later determination by Osborne (American Journal of Physiology, vol. 15, p. 333), confirmed by Abderhalden, gave 18.74 per cent.

While many of the figures of the foregoing table can not lay claim to a high degree of quantitative accuracy, it is, nevertheless, clear that the proportions of the various atomic groupings in the protein molecule vary within wide limits, while in some cases the most careful search has failed to show the presence of certain constituents. Thus, glycocol and lysin were not found in gliadin, nor lysin and tryptophan in zein, while ox muscle yielded a considerable percentage of lysin, a moderate amount of glycocol, and showed the presence of tryptophan.

ABSENCE OF CERTAIN CONSTITUENTS.

There is now a general agreement that in the process of digestion the proteins of the feed undergo extensive cleavage and are to a large extent broken down either into individual amino-acids or into comparatively simple peptid-like compounds. These substances are resorbed by the intestinal epithelium and the diverse proteins of the body are formed from them by synthetic processes, either in the intestinal wall or beyond. Such being the case, it has seemed clear that, for example, the proteins of ox muscle containing 2.06 per cent of glycocol and 7.59 per cent lysin could not be produced from gliadin, which is lacking in both these groups, nor from zein, which lacks lysin and tryptophan.

The classic example of the effects of such a deficiency is, of course, gelatin, which contains neither tyrosin, cystin, nor tryptophan. Bischoff and Voit¹

¹ Hermann's Handbuch der Physiologie, vol. 6, pp. 122 and 395.

long ago showed that gelatin in whatever amount fed is completely katabolized in the body, at least so far as its nitrogen is concerned, although it may somewhat diminish the waste of protein tissue. Subsequent investigations by Kirchmann¹ and by Krummacher² showed that when gelatin is fed alone an amount equivalent to the fasting nitrogen katabolism may reduce the loss of nitrogen from the body by something over 20 per cent, while, on the other hand, even very large quantities can effect a reduction of only about 35 per cent. Murlin³ finds that in the mixed diet of men about two-thirds of the protein may be replaced by gelatin without disturbing existing nitrogen equilibrium. That the inferior value of gelatin is due to the absence of certain groupings in its molecule seems to have been shown by Kaufmann,⁴ who found that gelatin with the addition of proper quantities of tyrosin, cystin, and tryptophan was able to maintain nitrogen equilibrium at least several days.

Investigations by Wilcock and Hopkins⁵ upon zein, which, as already noted, lacks lysin and tryptophan, approach the subject from a slightly different angle. They found that a diet containing zein as its only protein material was unable to maintain growth in young mice. The addition of tryptophan approximately doubled the survival period and added markedly to the well-being of the animals, but was unable to maintain life indefinitely. On the zein diet the animals became torpid early in the experiment and almost comatose before death ensued, while with the addition of tryptophan no such symptoms were observed. The authors interpret this result as showing that tryptophan has some specific function in the body aside from the mere maintenance of nitrogen equilibrium. The results recently obtained by Osborne and Mendel,⁶ however, show that great caution is necessary in the interpretation of such survival experiments, while they also indicate that growth is largely dependent on some other factor than the protein supply.

Experiments on rats by Henriques⁷ gave a similar result as regards zein, with which it was found impossible to obtain nitrogen equilibrium in short experiments. On the other hand, however, an abundant supply of gliadin maintained nitrogen equilibrium for some days, notwithstanding the fact that it lacks both lysin and glycocol.

PROPORTIONS OF CONSTITUENTS.

Still further, even when all the constituents of the body protein are present in the feed protein, their proportions may be widely different. Thus, a mixture of equal parts of glutenin and gliadin would contain about 30 per cent of glutamic acid as compared with about half that amount in ox muscle, while the latter yields over 11.5 per cent of leucin as compared with less than 6 per cent from the former. In such a case it would seem that the tissues in which the synthesis takes place must make a selection from the material supplied by the digestive tract, reportioning the various constituents, while the excess of certain ones would be attacked by the deamidizing enzymes of the body, their nitrogen being finally excreted as urea. Accordingly, it might be anticipated that the more nearly the feed protein resembled in its make-up the average of the body

¹ Zeitschrift für Biologie, vol. 40, p. 54.

² Zeitschrift für Biologie, vol. 42, p. 242.

³ American Journal of Physiology, vol. 19, p. 285; vol. 20, p. 234.

⁴ Archiv für die Gesamte Physiologie des Menschen und der Thiere (Pflüger), vol. 109, p. 440.

⁵ Journal of Physiology (London), vol. 35, p. 88.

⁶ Carnegie Institute of Washington, Publication No. 156.

⁷ Zeitschrift für Physiologische Chemie, vol. 60, p. 105.

proteins the more economically it could be utilized for the building up or repair of protein tissues, and that thus there might be very considerable differences in nutritive value between different proteins.

EXPERIMENTAL METHODS.

Considerations like the foregoing have been advanced by numerous authors, but as yet little satisfactory experimental work upon the relative values of the proteins has been reported. Indeed the problem is far from being an easy one. Aside from technical difficulties, it is, of course, a simple matter to substitute one protein for another in the ration; the difficulty lies in finding a satisfactory measure of the effects. The most obvious thing, of course, is a determination of the balance of income and outgo of nitrogen, which, when extended over reasonably long periods, affords an approximate measure of the relative gain or loss of protein. As has been clearly shown on preceding pages, however, the nitrogen balance, especially in a mature animal, is a more or less fluctuating thing, being materially affected by various factors besides the momentary protein supply. Especially important are the influence of the previous protein supply upon the general level of protein nutrition, the influence of the store of body fat carried by the animal, and the supply of available energy in the feed. Only after these influences have been eliminated as completely as possible can differences in the nitrogen balance be ascribed to differences in the nature of the proteins consumed. On this account, experiments in which additions of protein are made to a ration already containing a considerable supply and in which gains of nitrogen in different periods are made the basis of comparison are quite unsatisfactory, as Magnus-Levy¹ has pointed out. A more satisfactory basis of comparison is the amounts of the different proteins required to maintain nitrogen equilibrium under conditions otherwise comparable. Furthermore, the protein supply must not be too liberal. Protein supplied in excess of the minimum requirement is utilized largely as fuel material. Under such circumstances, it is easily conceivable that proteins differing widely in constitution may furnish enough of each of the essential cleavage products to meet the relatively small demand for the maintenance of tissue and that thus differences really existing may be masked by the excess of protein supplied.

These considerations clearly indicate that the most promising method of investigation is to compare the minimum amounts of the different proteins required, along with an abundance of nonnitrogenous nutrients, to maintain nitrogen equilibrium on as low a plane of protein nutrition as practicable in the same animal in like bodily states and under identical conditions, so far as it is possible to insure these. Any consistent differences appearing in a considerable number of trials may then, it would seem, be safely ascribed to differences in the nature of the proteins.

Thus far but three investigations, according to the general method just outlined, have been published, all of them appearing within the year 1909. For the present purpose it seems superfluous to review the older investigations, made by less satisfactory methods and in many cases from a different point of view.

MICHAUD'S INVESTIGATIONS.

Michaud² experimented on three dogs by substantially the method just outlined. Reasoning that any loss in transforming feed protein into body protein

¹ Von Noorden's *Handbuch der Pathologie des Stoffwechsels*, vol. 1, p. 78.

² *Zeitschrift für Physiologische Chemie*, vol. 59, p. 405.

would be smaller the less the difference in the constitution of the two, he used as his standard protein supply either dog flesh or the ground flesh and internal organs (heart, liver, spleen, and testicles) of dogs. This material may be assumed to have supplied the various amino acids, etc., in approximately the proportions required to maintain the protein tissues of the experimental animals with a minimum of loss. With this were compared gliadin and edestin as representatives of the vegetable proteins differing quite widely from those of the body and casein as an animal protein more or less similar to the tissue proteins.

The series of experiments on the first dog affords a striking illustration of the difficulties in the way of successful investigation of this question. After fasting for 16 days and receiving only nonnitrogenous feed¹ (sugar and lard) for 28 days more, the daily nitrogen excretion (feces and urine) was reduced to 1.42 grams per day and appeared to have become approximately constant. Quantities of the various protein materials containing this amount of nitrogen were then added in successive periods to the basal nonnitrogenous ration and the effect upon the nitrogen balance determined, the periods covering from 6 to 9 days each. In three periods in which dog flesh was fed, the animal gained small amounts of nitrogen (0.08 to 0.17 gram per day); in other words, an amount of protein equal to the fasting katabolism sufficed to produce nitrogen equilibrium. Practically the same result was also attained in the period in which "Nutrose" (a preparation of casein) was fed. Three periods with gliadin, on the contrary, showed in every case a loss of nitrogen ranging from 0.33 to 0.52 gram per day; that is, the gliadin appeared decidedly less valuable than the dog flesh or casein for the maintenance of the body protein. Upon adding more gliadin to the ration it was found necessary to increase the daily amount to the equivalent of about 3.5 grams of nitrogen before nitrogen equilibrium was reached.

At the conclusion of this series, however, two 3-day periods on the nitrogen-free ration (preceding and following the period with the larger amount of gliadin) showed that the prolonged feeding on rations poor in protein had so lowered the plane of protein nutrition that the daily fasting katabolism was now equivalent to only 0.95 gram of nitrogen, or on the average of the last two days of each period to only 0.82 gram. In other words, the 1.42 grams of the earlier periods did not represent the absolute minimum on which life could be maintained. A second series of trials was therefore instituted in which dog tissue was compared with casein and edestin. In no case was nitrogen equilibrium quite reached, but the dog flesh still showed a decided advantage over the other forms of protein. The dog, however, had become very much reduced and died during the final period on dog flesh, the autopsy showing an exceedingly anemic condition. The attempt to base the comparisons of the different proteins upon the absolute minimum of the protein katabolism, in other words, involved such a reduction in the stock of body protein and consequently such an abnormal condition of the animal as to render the value of the results questionable. In succeeding experiments on two other dogs, therefore, the attempt to reach the absolute minimum of the protein katabolism was abandoned and the amounts of the several proteins added to the basal nonnitrogenous ration were either made equivalent to the fasting katabolism in the first period or reduced slightly below it according to the judgment of the experimenter. The results were in accord with those of the first series, the vegetable proteins, gliadin and edestin, proving notably inferior to the dog flesh or the casein.

¹ No mention is made of any supply of ash ingredients other than those contained in the various forms of protein used, with the exception of a small amount of calcium carbonate (p. 423).

Upon two points, however, Michaud's results seem open to question.

First, the pure proteins which he employed, as well as the sugar and lard, can have contained but minimal amounts of ash, while, as already stated, no mention is made of the addition of any ash ingredients except calcium carbonate. In those periods, then, the animal was apparently in a state of partial or entire mineral hunger. The dog flesh (or in two periods horse flesh), on the other hand, contained its normal amount of ash, and it is not impossible that this was an important factor in determining its higher value, although it must be admitted that this explanation does not apply to the casein periods. Second, dog tissue or horse flesh is by no means pure protein, but in addition to ash constituents contains a great variety of organic compounds, which may have been quite as important as the protein. In other words, the periods on tissue are not comparable with those on pure proteins.

ZISTERER'S EXPERIMENTS.

Zisterer¹ has reported two series of similar experiments, also on a dog. They differed from Michaud's, however, in that the periods were shorter and that each feeding period was interpolated between two periods on a nonnitrogenous basal ration from the average results of which the fasting protein katabolism of the animal for that particular bodily condition was computed. Zisterer experimented with casein, wheat gluten, and lean meat extracted with water (muscle protein). He added to his rations the chlorids of sodium, potassium, and calcium, but no other ash ingredients. The ash content of the feeds was small. The energy supply in the feed was in every instance ample to supply the needs of the animal as computed according to E. Voit.² Taking the first period, on casein, as an example, the preliminary period on nitrogen-free feed covered five days and the one following the feeding period four days. On the average of the last two days of these periods, the fasting protein katabolism was equivalent to 1.975 grams nitrogen daily. During the intermediate 4-day period, casein containing 2.018 grams nitrogen per day was fed and the average daily nitrogen excretion for the last two days was found to be 2.333 grams. Two series of trials of this sort, made in inverse order, yielded the following results:

Protein metabolism of a dog—Zisterer.

	Fasting nitrogen katabolism.	Feed nitrogen.	Total nitrogen excretion.	Gain of nitrogen by animal.
Series I:	Grams.	Grams.	Grams.	Grams.
Casein.....	1.975	2.018	2.333	-0.315
Muscle protein.....	2.125	2.021	2.316	-.294
Wheat gluten.....	1.951	2.017	2.113	-.096
Series II:				
Wheat gluten.....	1.800	2.111	2.276	-.165
Muscle protein.....	1.806	2.110	1.903	+.207
Casein.....	1.708	2.108	2.050	+.058
Average:				
Casein.....	1.842	2.063	2.192	-.129
Muscle protein.....	1.966	2.066	2.109	+.043
Wheat gluten.....	1.876	2.064	2.195	+.131

If we represent the total nitrogen excretion upon the muscle protein by 100, that observed with the other proteins was as follows:

¹ Zeitschrift für Biologie, vol. 53, p. 157.

² Ibid., vol. 41, p. 113.

Relative nitrogen excretion on different proteins.

	Series I.	Series II.	Average.
Casein.....	101	108	104
Muscle protein.....	100	100	100
Wheat gluten.....	91	120	104

Compared in this way, the differences disclosed between the different proteins are small in themselves, and, especially in the case of the wheat gluten, are discordant in the two series. Apparently the differences are less than those which may be plausibly ascribed to variations in the conditions of the several experiments. The latter may be to some degree eliminated by comparing the total nitrogen excretion with the fasting nitrogen katabolism of the corresponding periods. If the latter be represented by 100, the relative nitrogen excretion on the several proteins was as follows:

	Series I.	Series II.	Average.
Casein.....	118.1	120.0	119.1
Muscle protein.....	109.0	105.4	107.2
Wheat gluten.....	108.3	126.5	117.4

This second method of comparison seems to indicate a distinct, although small, inferiority of the casein as compared with the muscle protein. The same is true of the average result with wheat gluten, but not of the results of the individual series. Entirely similar results are obtained if the calculation is made only upon the protein nitrogen of the feed and excreta instead of the total nitrogen. Zisterer's results are, of course, open to the same criticism made on Michaud's, viz, that the so-called muscle protein was not comparable with the pure proteins used in the other periods.

RESULTS ARE QUALITATIVE.

Both Michaud's and Zisterer's results are in a sense qualitative. They show that certain foreign proteins when substituted for tissue caused a relatively greater nitrogen excretion and were therefore less efficient in maintaining the nitrogen balance of the body. For gliadin and edestin, Michaud observed a notably greater difference than did Zisterer for wheat gluten. For casein their results are quite similar. In no case was the amount of foreign protein required to reach nitrogen equilibrium determined, with the exception of one short period upon gliadin in Michaud's experiments. In both cases, the differences appear relatively small. On the basis of average figures for the proportions of four of the principal amino-acids in the different proteins, Zisterer computes much greater possible differences. Representing the amount of muscle protein required to furnish a given amount of each one of the four amino-acids by 100, Zisterer calculates that the following amounts of casein and of wheat gluten would be required for the same purpose:

	Muscle protein.	Casein.	Wheat gluten.
To furnish equal amounts of:			
Alanin.....	100	444	267
Leucin.....	100	74	154
Glutamic acid.....	100	124	49
Tyrosin.....	100	47	102

As was noted above, the ash supply was but partially considered in Zisterer's experiments, no mention being made of the addition of ash ingredients with the exception of sodium, potassium, and calcium. It seems not impossible that the phosphorus compounds of the muscle protein may have had something to do with its apparently greater availability.

THOMAS'S EXPERIMENTS.

Thomas¹ has attempted to determine the relative values of the mixed proteins of different foods by a method differing somewhat from that employed in the two foregoing investigations. As has been shown in previous pages, on an abundant nonnitrogenous ration, especially of carbohydrates, the protein katabolism of the body may be reduced to a very low limit which represents more or less exactly the minimum amount of protein necessarily broken down in the vital activities. If a small amount of protein be added to such a non-nitrogenous ration, it will tend to be used to replace body protein, since the surplus of nonnitrogenous material tends to prevent its being katabolized to furnish energy. The extent, then, to which any given protein under these conditions diminishes the loss of protein from the body may be taken as the measure of its maintenance value. The principle of the method may be illustrated by the following supposititious case.

	On protein-free food.	On protein food.
Protein digested.....	0	4
Protein katabolized.....	6	7
Loss of protein from body.....	6	3

In this case, four parts of food protein obviously replace three parts of body protein and the percentage availability of the former is therefore 75. The principle of the method is similar to that of the determination of the percentage availability of energy (p. 27).

It is to be remarked concerning this method, first, that it assumes that the percentage availability of the food protein is the same for all amounts below the maintenance requirement; in other words, that it is a linear function. This is an unproved assumption, and in view of the readiness with which protein or its cleavage products in the body seem to be deamidized and utilized as fuel, the assumption seems of questionable validity.

Second, in applying the method it is necessary to know accurately the minimum amount of protein katabolized on a nitrogen-free diet, since any error in the determination of its quantity seriously affects the final result. The protein katabolism, however, under these conditions, is not a constant quantity, as has already been pointed out, but varies more or less, especially with the state of protein nutrition of the cells. Accordingly, it must be determined as accurately as possible for the subject at the time of the experiment, preferably immediately before and immediately after.

Third, the amount of protein fed must be less than that katabolized on the nitrogen-free diet. If an excess of protein be consumed, the additional amount will tend to be katabolized and used as fuel, thus rendering the comparison between the two periods illusory, since it is obvious that any such oxidation of protein would tend to make its availability appear too low. Thomas's experiments were made upon himself and included four series, two in May to

¹ Archiv für (Anatomie und) Physiologie, 1909, p. 219.

July and two in September to November of the same year. He determined his protein katabolism upon a nonnitrogenous diet (chiefly carbohydrates) in three or four day periods in each series and also interpolated single nitrogen-free days during each series. The results of these periods were more or less variable, but the final values employed by him, although representing to some degree an arbitrary selection of days, seem, on the whole, to fairly represent the nitrogen katabolism; that is, they satisfy the second of the two conditions above pointed out.

With these values for the protein katabolism were compared the nitrogen balances of periods of from two to four days (or in a few cases only one day) in which single foods were consumed along with sufficient carbohydrates and fat to fully supply the demands of the body for energy. The technic of these periods, however, can hardly be regarded as entirely satisfactory. Out of 33 days, the results of which are contained in his final table, the protein digested was greater than the average protein katabolism on the nitrogen-free days in 21 cases, the difference sometimes being considerable and sometimes relatively insignificant. As already pointed out, this tended to make the availability appear too low, and it is noteworthy that the excess of food protein is especially large in the experiments upon wheat flour which show a strikingly low availability. On the other hand, however, it is also true that a very low availability was found for maize protein in experiments in which but a slight excess was fed. In these experiments, however, the apparent digestibility of the protein was remarkably low, ranging from 56 to 69 per cent, but a similar low digestibility (about 68 per cent) was found in the trials with rice. Furthermore, the periods were relatively short and in many instances the nitrogen intake varied considerably within the period, so that it may be questioned whether the nitrogen excretion reached a stable value. Moreover, to some extent there was a more or less arbitrary selection of days to be compared. For all these reasons Thomas's results must be accepted with more or less reserve.

His final results for the percentage availability of the protein of different materials are as follows, the results being calculated in three different ways, viz:

A. Fecal nitrogen all regarded as derived from the food, that is, the comparison is made upon the basis of the apparently digested protein.

B. Fecal nitrogen regarded as being all present in the form of metabolic products.

C. One gram of fecal nitrogen is regarded as derived from metabolic products and the remainder from undigested food.

Relative availability of proteins—Thomas.

	A.	B.	C.
Lean beef.....	104.94	103.75	.....
Milk.....	106.51	105.73	.....
	99.65	99.71	.....
Fish.....	103.09	102.06	.....
	85.73	89.37	.....
	88.17	91.95	.....
Rice.....	83.00	88.53	87.09
	86.26	90.73	89.55
Crabs.....	72.60	78.85	.....
	73.38	79.45	.....
Yeast.....	56.63	73.48	69.58
	53.40	70.35	71.45
Casein.....	66.69	70.14	67.12
Nutrose.....	63.45	69.02	.....
	29.17	36.25	.....
	36.70	43.04	.....
Wheat flour.....	64.50	42.04	.....
	41.35	51.10	48.97
	27.74	39.75	36.94

Relative availability of proteins—Thomas—Continued.

	A.	B.	C.
Potatoes.....	56.37 64.50 73.00 80.33 77.04	 83.18	68.80 72.67 78.72 76.22
Cauliflower.....	78.66 80.68	..... .....	77.45 87.78
Spinach.....	77.62	.....	83.88
Peas.....	64.50	.....	63.83
Cherries.....	49.58 51.64	59.89 59.89	55.15 56.01
Maize.....	66.42 24.55 12.25	..... ..... .....	78.57 40.47 29.52 3.54

In Zisterer's experiments, summarized on page 104, the feed nitrogen is so slightly in excess of the fasting nitrogen katabolism that it would seem that no large error would result from applying Thomas's method of computation. The results are as follows:

Percentage availability.

	Series I.	Series II.	Average.
Casein.....	82.26	83.77	83.02
Muscle protein.....	90.60	95.40	93.00
Wheat gluten.....	91.97	77.45	84.71

The results as thus computed are not widely different from those obtained by Thomas for casein and meat protein, but are slightly higher than his results for wheat protein. Michaud's results do not lend themselves to computation in this way.

Another recent investigation of a different character may be mentioned for the sake of completeness, viz, that on frogs by Busquet,¹ who compared lean veal and mutton with frog meat as regards the amount required to maintain the live weight or to produce a unit of gain of weight in previously fasting frogs. In this respect the veal and mutton were found distinctly inferior to the frog meat per unit of dry matter.

SIGNIFICANCE OF RESULTS.

In the comments upon the individual experiments, it has already been clearly indicated that they are open to criticism in many respects, such as the noncomparable nature of the protein supply, the lack of due consideration of the supply of mineral matter, etc. Moreover, nearly all the experiments were of relatively short duration.

Taking the results at their face value, however, they seem to indicate distinct differences in the nutritive values of proteins. The entire lack of certain groups, as in the case of gelatin and zein,

¹ Journal de Physiologie et de Pathologie Générale, vol. 11, p. 399.

seems to render impossible a complete substitution for tissue protein, while differences in the proportions of the different amino acids apparently result in differences in the replacement values of the proteins, although these differences, especially in the experiments of Michaud and Zisterer, are hardly as great as might have been expected. What now can be said regarding the probable significance of these differences for the ordinary problems of nutrition?

In the first place, it is to be remarked that both man and animals consume a mixture of proteins. The meat eater gets, along with his gelatin, the various muscle proteins. The animal fed on maize alone receives not only zein but its associated proteins, amounting, according to Osborne,¹ to about 40 per cent of the total protein of the grain, whose chemical constitution has not yet been reported. In the ordinary mixed rations of domestic animals it would appear that there must be a considerable degree of compensation between the different proteins as regards the proportions of the different cleavage products supplied to the organism, although it is difficult to judge to what extent this is the case. In view, however, of the rather small differences observed with pure proteins, it may be questioned whether such differences as exist in mixed rations are of very much significance.

In the second place, the observed differences in proteins were obtained in experiments in which small amounts of protein were consumed and in which the animals were on a low level of protein nutrition. As was pointed out in the discussion of those experiments, the consumption of protein in excess of the maintenance requirement, such as usually occurs with domestic animals, tends to obscure the differences between the proteins, owing to the considerable extent to which protein serves for fuel purposes under those conditions.

Third, almost all writers upon this subject tacitly assume the inability of the body to change one amino-acid into another. It does not appear that there is adequate proof of this inability. Most of the amino acids concerned belong to the aliphatic series of compounds, characterized by a straight carbon chain, and as between these compounds, at least, mutual changes are not difficult to conceive. As a matter of fact one such change appears to have been demonstrated. It is well known that when benzoic acid is consumed it is paired in the body with glycol, forming hippuric acid which is excreted. It seems to be well established that with large amounts of benzoic acid more combined glycol may appear in the excreta than can be assumed to have been present as such in the amount of protein katabolized during the same time. In this case, apparently, the body is able to manufacture glycol from some other substance, pre-

¹ Journal of the American Chemical Society, vol. 19, p. 532.

sumably from the amino-acids containing a larger number of carbon atoms. Whether a change in the opposite direction, that is, a synthetic change, can take place can be at present only a matter of speculation, but such a change would be entirely analogous to the building up of the fatty-acid chains from carbohydrates, which is a common occurrence in the body. Moreover, Knoop,¹ and Embden and Schmitz² have found that certain amino acids may be formed synthetically from the corresponding fatty acids and ammonia, thus indicating a possible chemical mechanism by which a deficient supply of some one amino-acid might be to some extent overcome. While, therefore, we can hardly suppose that the proportions of the different cleavage products is a matter of entire indifference, we can easily imagine that there may be more or less transformation of one into another in case of need.

Finally, there is the possibility that in the absence of some one amino-acid from the feed, the corresponding acid resulting from the katabolism of protein tissue may to a greater or less extent escape the action of the deamidizing enzymes and be regenerated to protein. This would obviously be quite in accord with the conception of the protein metabolism as a complex of reversible enzym reactions which was outlined on page 87.

¹ Zeitschrift für Physiologische Chemie, vol. 67, p. 489.

² Biochemische Zeitschrift, vol. 29, p. 423.



[Reprinted from The Journal of the American Chemical Society,
Vol XXXIV. No. 5. May, 1912.]

[CONTRIBUTION FROM THE INSTITUTE OF ANIMAL NUTRITION OF THE PENNSYLVANIA
STATE COLLEGE.]

ADIABATIC DEVICE FOR BOMB CALORIMETER.

By J. A. FRIES.

Received January 29, 1912.

The value of an adiabatic equipment to a bomb calorimeter lies in the fact that such a device, if only simple enough, may be a means both of saving time and of greater accuracy in determining the heat of com-

bustion. It does away with much tedious computation, and the correct temperature of the calorimeter before and after a combustion is more readily obtained.

Adiabatic devices differing in principles have been described by Richards, Henderson and Trevert,¹ and Benedict and Higgins,² but since these, however valuable in themselves, are not made so as to be easily adjusted to bomb calorimeters that are already installed and in use, a simpler device was sought for to fill that want.

The problem was satisfactorily solved by applying to the bomb calorimeter the same principle which is used in the respiration calorimeter according to Atwater and Rosa. Any bomb calorimeter of the Atwater-Berthelot type can be made adiabatic without much expense by a simple device.

The materials which were used in the construction of the apparatus were such as could be picked up around the laboratory. Hence it is not so much the material as the principle which I want to emphasize.

The following is a description of the arrangement for making the bomb calorimeter adiabatic:

Heating Device.—This consists of a German silver wire about 3.5 meters long and 0.8 mm. in diameter, having a total resistance of about 6.1 ohms. This wire was strung through small brass eyelets screwed directly into the inner insulating fiber jacket of the modified Atwater-Berthelot bomb calorimeter which we are using. The eyelets were so arranged that there was one coil of wire near the bottom a little distance from the sides, the rest of the wire then going up and down along the sides making eight loops spaced as evenly as convenient and coming to within 30 mm. of the top of the inner fiber jacket. The two ends were fastened to insulated copper wire and brought out through the side of the fiber jackets. It was wired in this fashion in order to avoid any induction by the current. Both direct and alternating currents have been tried. At present we use only alternating current. The current which suits this particular wire, or resistance, and which will give the heat needed quickly enough is taken from a 110 volt circuit through five 32 c. p. carbon filament lamps in parallel. The distance between heating wire and fiber vessel is about 6 mm. on the average, leaving 15 to 20 mm. between wire and calorimeter.

With this device alone, however, it was found impossible to measure the true rise in temperature of the air quickly enough by means of mercury thermometers to make possible any use of it in connection with the heat measurements.

Air Thermometer.—Mercury thermometers being found useless for

¹ *Proc. Amer. Acad. Arts and Sci.*, 42, No. 21 (March, 1907).

² *THIS JOURNAL*, 32, 461 (1910).

measuring the air temperature, and electric thermometers being difficult and costly to instal, it was finally decided to use an air thermometer. Besides securing a quick registration of the resulting rise in temperature, it was also necessary to provide some way to regulate the heating effect upon the calorimeter and make it uniform. To use any kind of blower would complicate matters, but the problem was solved by placing the calorimeter inside a double walled copper jacket which constitutes the bulb of the air thermometer.

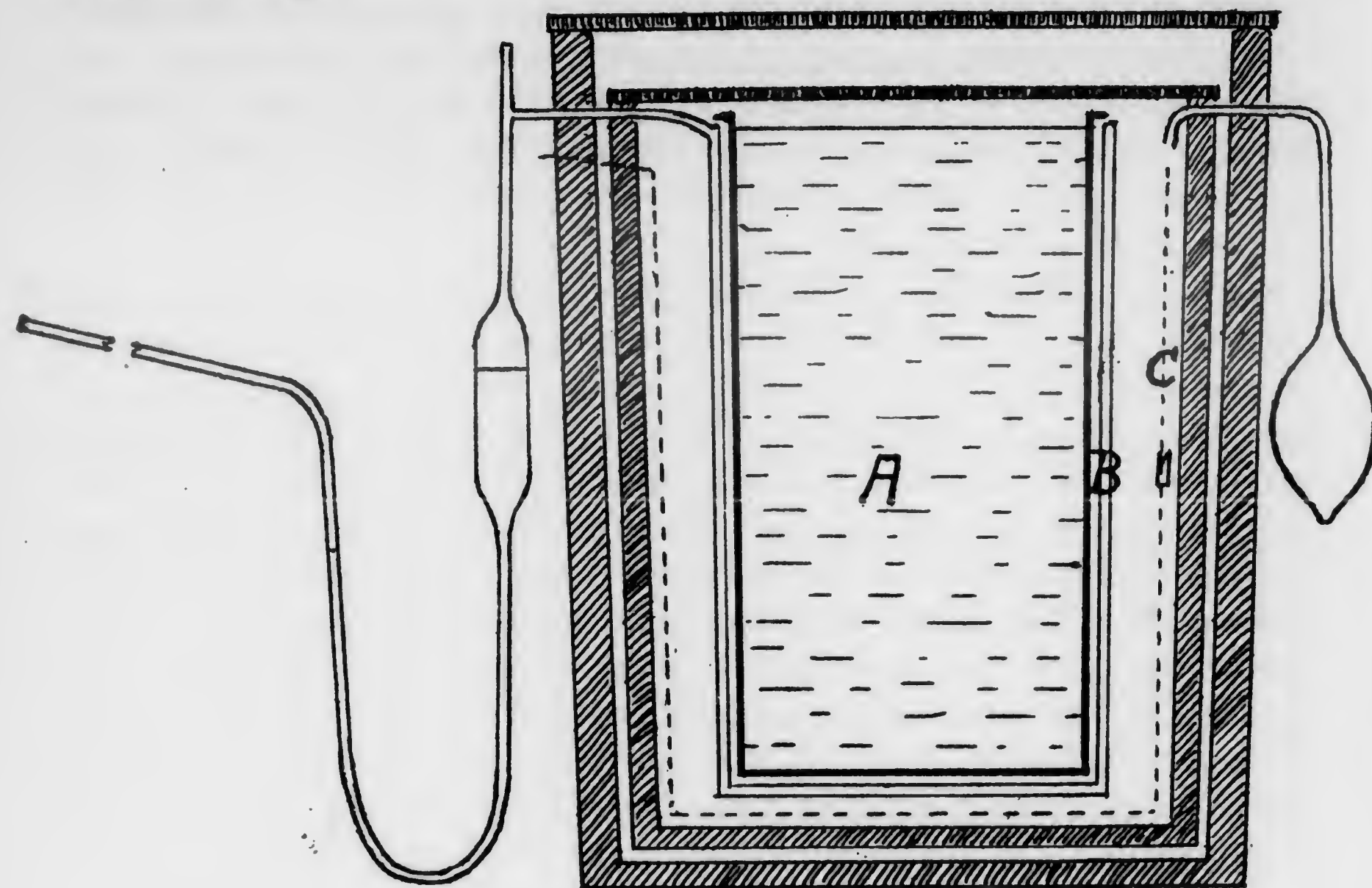
Copper Jacket.—This double walled cylindrical copper jacket was made of polished sheet copper about 0.25 mm. thick and has a 4 mm. air space between the walls and bottoms. In the bottoms there are three holes through which project three screw heads on which the calorimeter rests. The diameter of this jacket is such that when the calorimeter is in place there is an air space of about 4 mm. between the calorimeter and copper at the sides and 5 mm. at the bottom, and the upper edge of the copper is on the same level as the upper edge of the calorimeter. The copper jacket rests on three corks and is held in position by corks at the sides, and the calorimeter is kept in its position within the jacket by means of a few pasteboard blocks glued on the sides of the copper. Care must be taken that the different metals do not touch at any point.¹ At the upper edge a small brass tube is soldered into the copper and connected by good rubber to a piece coming through the fiber walls from the outside. When this air-tight jacket has once been placed in position, it remains as a permanent part of the apparatus.

Tube and Water Reservoir.—The thermometer consists, besides the copper jacket, of a glass tube, bore about 2 mm., which is placed at an angle of about 14 degrees. It is bent in U shape at the end near the jacket and from the bend to the extremity is 85 cm. long. The tube is supported against a fixed strip of wood, which also serves as a support for the calibrated paper scale. Between the brass tube coming from the apparatus and the end of the glass tube, the bulb of a 25 cc. pipet is inserted. This pipet bulb serves as a reservoir for the water (colored with litmus) which serves as the indicating column, and the total water in the system should not be quite sufficient to fill the bulb. This is to prevent the water from being drawn into the jacket should the temperature ever go below the range of the thermometer.

With the copper jacket and tube, as described, one degree change in temperature equals 12.5 cm. on the glass tube. This was considered sensitive enough, although the air thermometer can be made more or

¹ It may be stated that in order to make it convenient to lower the calorimeter filled with water into the copper jacket a depression is made on each side at the upper edge of the jacket so that the fingers can grip conveniently over the edge of the calorimeter when handled.

less sensitive by using a smaller or larger bore tube, or by placing it at a different angle.



A = Calorimeter with water.
B = Double-walled copper jacket.
C = Resistance wire.

Calibration of the Air Thermometer.—This air thermometer is sensitive both to heat and barometric pressure, but since the latter rarely changes materially during the short time required for a heat determination no correction for pressure is necessary.

In order, however, to provide for the use of the full range of the Beckmann thermometer the glass tube must be a little longer than is needed for the given number of degrees, so as to allow for some changes in the atmospheric pressure. Should the barometric pressure change considerably during the day the air thermometer can be adjusted to the existing temperature and pressure conditions in a moment by opening the air valve on the brass pipe just outside the fiber jacket. The amount of water in the tube should be such that when the air valve is open the water column stands a little above the bend of the tube. To prepare the scale representing centigrade degrees a good mercury thermometer on which 0.01° can be estimated by aid of a lens is placed in the copper jacket, the covers are put on, and the apparatus allowed to stand until the conditions have reached constancy. The air valve is then closed, the thermometer lifted up and read and the position of the water column marked.

Heat is then applied by means of the electric current and the water column is kept constant at another point until the mercury thermometer standing in the copper jacket has reached a maximum. This point is marked and the corresponding rise in temperature of the jacket is noted. This operation is repeated until a sufficient number of points have been established to permit the making of the scale which should be graduated at least to 0.1° . If the calibration is extended over considerable periods of time during unsettled weather conditions, the barometric pressure should be noted and corrected for, if necessary.

Being affected by two factors, heat and pressure, a fixed scale is of no value, a movable one must be used, one that can be set to any point within several degrees. In order to have the degrees of equal length upon the tube, care must be taken in selecting one having a uniform bore.

Sensitiveness.—The long space on the scale equal to a tenth of a degree makes it easy to estimate to a hundredth of a degree by the naked eye at some little distance away. The heating effect of the electric current, previously referred to, may be seen from the following table which gives the time of the current in seconds, and the rise in temperature of the air thermometer at different intervals. These results may vary somewhat with the temperature condition of fiber jackets and surrounding air, as well as with changes in voltage.

TABLE I.

Current in seconds.	Rise in temperature in		
	30 seconds. °C.	1 minute. °C.	Total. °C.
20	0.28	0.58	0.76
25	0.35	0.78	1.05
30	0.52	0.95	1.35
35	0.52	1.17	1.63
40	0.52	1.37	1.81
45	0.52	1.58	2.00

In about $1\frac{1}{2}$ minutes after the current is off, the water column has practically ceased to rise and in 3 to 4 minutes the maximum rise is reached. Here it remains constant for some minutes before it begins to fall again, so that unless one wishes to take the readings of the calorimeter temperature for a longer period than 3 or 4 minutes after the maximum has been reached, it is not necessary to hold the temperature of the air thermometer constant by further short contacts.

When a charge is ignited in the bomb, the Beckmann thermometer will begin to show a rise in 10 seconds, increasing so that the most rapid rise is between 30 and 60 seconds after ignition. In 30 seconds after ignition of a substance in the bomb the heat from the calorimeter is beginning to show on the air thermometer.

The air thermometer begins to show the effect of the heating current in less than 8 seconds, and sooner when the air between copper and fiber jacket is stirred by means of a rubber bulb. The effect which this heating has upon the calorimeter may be seen from the following observations, giving the change in calorimeter temperature per minute which took place during a given period of time with a given difference between the average of the air and calorimeter thermometers.

During these tests the calorimeter contained the bomb and 2000 grams of water, which was stirred as during a heat determination.

TABLE II.—TEMPERATURE VARIATIONS IN CALORIMETER DUE TO DIFFERENCE BETWEEN ITS TEMPERATURE AND THE SURROUNDING AIR TEMPERATURE.

Minutes.	Temperature of calorimeter water.	Average of air thermometer.	Difference.	Change in calorimeter temperature per minute.
1st to 4th	24.182°	24.40°	0.22°	0°
5th to 11th	24.190	24.97	0.78	+0.0025
12th to 16th	24.207	25.25	1.04	+0.0035
1st to 9th	24.086	23.96	-0.13	-0.0008
10th to 13th	24.080	24.00	-0.08	-0.0004
14th to 5th	26.040	25.20	-0.84	-0.0050
6th to 8th	26.023	25.73	-0.29	-0.0035
9th to 14th	26.017	25.96	-0.06	-0.0008

In these short tests the temperature of the calorimeter was about 0.5° above that of the fiber jackets in the case of the first five, and about 2.5° above in the last three.

From the foregoing figures we see that with the air thermometer 0.22° above that of the calorimeter no change was observed in the calorimeter temperature during four minutes. When heat was applied so that the air thermometer registered 0.78° on an average more than the calorimeter temperature there was a rise of 0.0025° per minute, etc. On the other hand we see a drop in the temperature of the calorimeter when the air thermometer was allowed to fall below that of the calorimeter. At the upper limit of the scale and with the abnormally great difference in temperature between the calorimeter and fiber jackets the drop in the calorimeter temperature was relatively somewhat greater than in the first cases.

Tests of the Apparatus.—The purpose of the adiabatic device is to prevent loss of heat from the calorimeter when its temperature is raised above that of the surrounding media during a determination. A test, therefore, of the efficiency of the arrangement would be to be able, by the use of it, to hold the calorimeter temperature constant when it is higher than the room temperature and that of the rest of the apparatus.

Of the three tests of longer duration given below, one (a) was made near the upper limit of the scale, with a difference of about 1.5° between the calorimeter and the rest of the apparatus. In another trial (b),

near the lower limit of the scale, there was a difference of about 0.5° between the calorimeter contents and the fiber jackets and covers. A third trial (c) is given in which the temperature of the bomb contents was adjusted practically to that of the room and the rest of the apparatus. In this case no heat was applied, the water being stirred as in a determination of heat of combustion. Under these conditions there should be no change in the temperature anywhere. Having no automatic heat regulator in the room, perfect test conditions could not be obtained but they were sufficiently so for our purpose.

TABLE III.

Minutes.	(a)		(b)		(c)	
	Calorimeter temperature.	Air thermometer.	Calorimeter temperature.	Air thermometer.	Calorimeter temperature.	Air thermometer.
1st	25.189°	25.35°	21.358°	21.47	21.491°	21.48°
3rd	25.189	25.34	21.358	21.47	21.491	21.48
5th	25.189	25.34	21.358	21.47	21.491	21.49
7th	25.189	25.34	21.358	21.47	21.491	21.49
9th	25.190	25.33	21.359	21.47	21.491	21.49
11th	25.190	25.30	21.358	21.44	21.492	21.49
13th	25.190	25.29	21.357	21.46	21.492	21.49
15th	25.190	25.29	21.357	21.46	21.493	21.49
17th	25.190	25.28	21.357	21.47	21.493	21.49
19th	....	...	21.357	21.48	....	...
21st	....	...	21.357	21.49	....	...
24th	....	...	21.357	21.50	....	...

In (a) and (b) of the above tests the calorimeter and its contents were warmer than the rest of the apparatus when placed in position. After being placed in position and the stirrer started the heat was applied gradually until the air thermometer registered as noted in the table.

At the beginning of test (a) when the air thermometer registered 0.16° above that of the calorimeter the temperature of the latter remained constant for 5 minutes. After that there was a tendency of the calorimeter temperature to rise, but it remained constant when the difference in temperature was gradually falling, until at the end of the test it was but 0.10°. With a difference of 0.11° in the beginning of test (b) the temperature of the calorimeter remained constant for 9 minutes. Only a slight cooling of the air caused a drop in the calorimeter temperature, but with a difference of 0.13° the temperature again remained constant.

The fact that it is necessary to have the air thermometer read 0.10–0.16° higher than the calorimeter in order to keep the latter at a constant temperature may be ascribed to the fact that there is a constant radiation of heat from the water surface and top of the calorimeter to the colder air and covers. It being impracticable to extend the copper jacket over the top, extra heat must be supplied through the sides and bottom of

the calorimeter to compensate for the loss of heat at the top and keep the whole system in equilibrium.

This necessary difference in temperature will no doubt vary with each instrument while, as the foregoing results show, and as would be expected, it is greater the greater the excess of the calorimeter temperature is over that of the surroundings. When working under uniform conditions, a little experience will soon show what excess is necessary.

In test (c) of Table III, no heat was applied, but the water in the calorimeter was stirred as during the other tests. After the fourth minute the air thermometer remained constant, but the calorimeter temperature rose 0.002° in 17 minutes. This slight rise in the calorimeter temperature can only be ascribed to one of two causes. It must either be due to heat generated by the stirrer or else due to increase in barometric pressure affecting the reading of the air thermometer. The writer inclines to the latter explanation, although during these tests the weather was rainy and, hence, there is a possibility that the heat produced by friction of the stirrer may have exceeded the loss of heat due to evaporation of water, which under ordinary winter conditions, judging from common observations only, appears to exceed that produced by friction of the stirrer.

Rise in Temperature Due to Combustion.—For the particular bomb calorimeter in question the rise in temperature due to a definite number of calories generated in the bomb may be seen in the following table:

TABLE IV.—RISE IN CALORIMETER TEMPERATURE WHEN HEAT IS GENERATED IN THE BOMB.

Heat generated. Calories.	Rise first minute.	Total rise.
5000	1.60°	2.06°
4500	1.35	1.86
4000	1.10	1.65
2000	0.56	0.80

The rise in temperature during the first minute may vary slightly according to the nature of the substance ignited.

Manipulation.—While the bomb is gotten ready for a determination, both covers of the apparatus are kept in position and a good mercury thermometer is allowed to stand in the copper jacket. When the bomb has been charged with oxygen, and the necessary amount of water, a little warmer than the apparatus, has been put in the calorimeter, the air valve is closed, the temperature of the air in the apparatus is taken, and the scale set so that the end of the water column will indicate that temperature. The covers are now removed, calorimeter and bomb placed in position and stirrer started. After a couple of minutes raise the air thermometer readings, by making short contacts, to 0.10° to 0.15° above the reading of the Beckmann thermometer in the calorimeter

water. Take a reading or two to be sure that the calorimeter temperature remains constant. Ignite the charge and at the same time close the switch on the heating circuit.

The length of time during which the current should be on depends upon the amount of heat generated in the bomb. If, for instance, we expect about 4500 calories, a glance at Table IV shows that the total rise in temperature will be 1.86° and about 1.35° at the end of the first minute. From Table I we see that the current on for 40 seconds with perhaps one or two additional short contacts will meet the conditions. Whether the total current should be on continuously for that length of time, or whether under any conditions it would be of advantage to make shorter contacts with some seconds of time between, experience will soon decide.

Readings of the thermometers are taken as usual every minute. The maximum temperature will be obtained in from 3 to 5 minutes according to the charge. In most cases 4 minutes decides the maximum rise, but a couple more readings should be taken to make sure that the temperature is constant.

Computation.—The computations are much simplified by this method of determination. Only the reading of the Beckmann thermometer taken at the time of ignition and the maximum reading after ignition, usually at the fourth minute, receive the thermometer corrections. The true temperature difference is multiplied by the water equivalent of the apparatus, and from this product is subtracted the heat due to the iron wire or other material used for ignition and the acid formed during the combustion.

Cooling the Apparatus for the Next Determination.—As determinations are usually made with the bomb calorimeter, considerable time elapses between the ignitions, and the copper jacket and air wall acquire the room temperature without any further attention. To hasten the lowering of the temperature, a small toy fan, 5 inches in diameter, and driven by 2 to 3 dry batteries, can be placed above the apparatus for a few minutes, or a beaker or other vessel with cold water may be set down in the copper jacket for a little while. The covers are then put on, the mercury thermometer replaced and the apparatus allowed to stand to be ready for the next determination.

Energy Determinations Influenced by Air Temperature.—The following table gives the difference in temperature between the calorimeter and the surrounding air space at different times during the determination and also the results obtained for the heat of combustion of benzoic acid.

These four determinations show a range of air temperature conditions within which it is easy to keep the apparatus and the results come practically within the limit of analytical error, the theoretical value of benzoic

TABLE V.—AIR TEMPERATURE ABOVE OR BELOW THE CALORIMETER TEMPERATURE.

At time of ignition. ° C.	1 minute after ignition. ° C.	Average during 4 minutes. ° C.	Calories per gram ben- zoic acid.
+0.34	—0.25	+0.13	6323.0
+0.11	—0.15	+0.01	6315.0
+0.16	+0.05	+0.16	6316.3
+0.13	—0.25	+0.13	6323.3

acid being 6320 calories according to the U. S. Bureau of Standards. These results show that the adiabatic arrangement is very sensitive and capable of giving very good results.

STATE COLLEGE, PA.

Reprinted from the American Journal of Physiology.

Vol. XXXI. — January 1, 1913. — No. IV.

THE INFLUENCE OF STANDING OR LYING UPON THE METABOLISM OF CATTLE.¹

By HENRY PRENTISS ARMSBY AND J. AUGUST FRIES.

[Investigations at the Institute of Animal Nutrition of the Pennsylvania State College in co-operation with the Bureau of Animal Industry of the United States Department of Agriculture.]

IN a number of previous publications² we have called attention to the very marked increase in the total metabolism of cattle in the standing as compared with the lying position which has been uniformly observed in our experiments. In thirty-seven published experiments this increase varied from a minimum of 28.3 per cent to a maximum of 64.5 per cent, averaging 41.4 per cent, and a considerable number of unpublished experiments have given entirely similar results. The foregoing figures refer primarily to that portion of the total heat which was given off by radiation and conduction and do not include that eliminated by means of the evaporation of water. On various grounds, however,³ it was assumed, in discussing the experimental results, that the proportion of the total heat produced which was carried off as latent heat of water vapor was essentially the same in the standing and lying positions, and the results of the experiments were computed upon the basis of this assumption.

Such an increase in metabolism as a result of standing is quite in accord with the results of numerous previous investigations, espe-

¹ Presented before Section 7 of the Eighth International Congress of Applied Chemistry. As presented before the Congress, the paper included only the results of Periods II, III, and V, but these were given in greater detail. In the present paper some minor corrections have been made in the figures for Period V, as well as a few verbal changes in the text.

² United States Department of Agriculture, Bureau of Animal Industry, Bulletin No. 51 (1903), p. 35; No. 74 (1905), p. 21; No. 101 (1908), p. 20; No. 128 (1911), p. 42.

³ Compare especially United States Department of Agriculture, Bureau of Animal Industry, Bulletin No. 128, pp. 122-124.

cially upon man. Thus Katzenstein⁴ in experiments upon himself observed an increase in the oxygen consumption varying from a maximum of 32 per cent to practically zero when standing with the least possible muscular exertion. Zuntz⁵ in experiments on a dog observed an increase of 40.9 per cent in the oxygen consumption and one of 36.5 per cent in the carbon dioxid excretion in the standing as compared with the lying position. Bornstein and Ott⁶ in experiments on themselves found an increase of 6.6 cal. and 11.8 cal. per hour, respectively, in the computed heat production when standing over that when lying. Widlund,⁷ on the other hand, obtained but a slight increase in the carbon dioxid excretion in standing as compared with lying. Benedict and Carpenter,⁸ as the average of a number of experiments comparing sitting with standing, find an increase in the latter of 12 per cent for carbon dioxid, 16 per cent for oxygen, and 17 per cent for heat production. Hagemann⁹ in two experiments on cattle reports increases of 23 per cent and 27 per cent in the total heat production in standing as compared with lying.

Quite recently, however, Zuntz¹⁰ has called attention to the apparently small influence of standing and lying upon the metabolism of the sheep, observed in experiments by Hagemann¹¹ in which the difference in the heat production as computed from the respiratory exchange was only 8 per cent. Dahm,¹² working in Zuntz's laboratory and by his methods, likewise found an increase of only 8 per cent in the respiratory excretion of carbon dioxid by a young bull when standing as compared with that when lying. Zuntz points out that even with a uniform rate of heat production the heat emission would tend to be less in the

⁴ KATZENSTEIN: Archiv für die gesammte Physiologie, 1891, xlix, pp. 361-362.

⁵ ZUNTZ: *Ibid.*, 1897, lxviii, pp. 194-195.

⁶ BORNSTEIN and OTT: *Ibid.*, 1905, cix, p. 621.

⁷ WIDLUND: Skandinavisches Archiv für Physiologie, 1905, xvii, p. 290.

⁸ BENEDICT and CARPENTER: Carnegie Institution of Washington, Publication 126, 1910, pp. 243, 253.

⁹ HAGEMANN: Landwirthschaftliches Jahrbücher, xli, Ergänzung, i, pp. 41, 128.

¹⁰ ZUNTZ: Medizinische Klinik, 1910.

¹¹ HAGEMANN: Archiv für Physiologie, Supplement Band, 1899, p. 111.

¹² DAHM: Biochemische Zeitschrift, xxviii, p. 494.

lying posture, since less of the animal's surface is exposed for radiation and evaporation, and is inclined to attribute the discrepancy between our results and those of Hagemann and of Dahm to this effect. In other words, Zuntz believes that the differences in the heat emission observed in our experiments are much exaggerated by a storing up of heat, during the intervals of lying, in the platform upon which the animal rests or in the body of the animal itself, this heat being given off again in the succeeding intervals of standing.

That there must be a tendency in this direction is undeniable, but we have not believed the effect to be of sufficient magnitude to affect seriously our comparisons of the metabolism in the two positions. There must necessarily be a limit to the amount of heat which can be stored up in the platform in this way, and it is easy to find in our experiments comparatively long intervals of lying in which, if Zuntz's explanation of the results be accepted, there must have been a storage in the platform of two or three times as much heat as it can be computed to have retained even upon the most extreme assumptions. Moreover, such an accumulation of heat in the platform would necessarily tend to increase radiation from the latter so that the heat emission during lying should tend to increase until it reached the level of the actual production by the animal. As a matter of fact, we have failed to find any distinct tendency of this sort in our experiments. Indeed, the heat emission during the periods of lying tends to be very uniform — more so, in fact, than during the periods of standing.

Obviously, however, arguments like the foregoing cannot be conclusive, and it still appeared possible that in comparisons between shorter intervals of standing and lying the difference in the heat emission as measured might be considerably greater than that indicated by a comparison of the gaseous exchange. In order to test this, appliances have been devised which permit the separate determination of the carbon dioxid and water vapor excreted in the intervals of standing and lying, respectively, and the present paper is a preliminary report upon the results obtained.

The experiments were made with the respiration calorimeter of the Institute, which is a modification of the original Atwater-Rosa apparatus for experiments on man.¹³ The apparatus is essentially a respi-

¹³ United States Department of Agriculture, Office of Experiment Stations, Bulletin No. 63 (1899).

ration apparatus of the Pettenkofer type with the addition of appliances for the determination of the heat emitted by the animal under experiment. A general description of the apparatus has been more than once given,¹⁴ and a recent publication¹⁵ describes in considerable detail the experimental methods pursued in these investigations. Repeated check tests in which pure alcohol was burned in the apparatus have shown that the results obtained may be regarded as accurate within the following percentages of the total amounts determined:

Carbon dioxid	0.5 per cent
Water vapor	6.0 " "
Heat	1.0 " "

For the special determinations of carbon dioxid and water vapor here reported, samples of both the ingoing and outcoming air are taken by means of rotary blowers. Each sample passes through an absorption train in which the carbon dioxid and water are absorbed and weighed, then through the blower, which is immersed in an oil bath, and finally through a calibrated metre (made by the Daansk Maalerfabrik, Copenhagen) which records the volume of the sample. By means of a series of valves coupled together the two currents of air may, at the instant when the animal stands up, be shunted from one absorption train and metre to another, while when he lies down again the current may be shunted back to the first series. In this way the aggregate excretion of carbon dioxid and water vapor for the experimental period in the two positions is determined. At each change of position samples of the air in the chamber of the apparatus are also taken for determination of the residual carbon dioxid and water vapor.

The results here reported were obtained in a series of experiments with a steer upon alfalfa hay and the so-called "alfalfa meal" (finely ground alfalfa hay). Each experiment extended over forty-eight consecutive hours (exclusive of five or six preliminary hours), covering the eighteenth and nineteenth days of a twenty-one-day feeding

¹⁴ United States Department of Agriculture, Bureau of Animal Industry, Bulletin No. 51 (1903); Experiment Station Record, No. 15 (1903-1904), p. 1037; Bureau of Animal Industry, Twenty-third Annual Report (1906).

¹⁵ United States Department of Agriculture, Bureau of Animal Industry, Bulletin No. 128 (1911), pp. 200-222.

period, and was divided into four subperiods of twelve hours each, the results for which are given separately. The rations consumed were:

Period I	7.5 kg. alfalfa hay
Period II	7.5 kg. alfalfa meal
Period III	6.0 kg. alfalfa hay
Period IV	6.0 kg. alfalfa meal
Period V	3.5 kg. alfalfa hay
Period VI	3.5 kg. alfalfa meal

The rations of Periods III and IV were estimated to be approximately maintenance rations. The subject was a pure-bred short-horn steer about twenty months old, in moderate condition, and weighing about 360 kg.

There were rather frequent changes of posture on the part of the animal, which would tend to emphasize any effect of a storing up of heat in the platform upon the partition of the heat emission between the standing and lying intervals.

In Period I there were twenty intervals of standing, varying from eight to one hundred and thirty-six minutes each, and twenty-one intervals of lying, varying from twenty to one hundred and thirty-three minutes each. In Period II there were seventeen intervals each of standing and lying, the length of the standing intervals varying from eighteen to one hundred and forty-seven minutes and that of the lying intervals from seventeen to one hundred and sixty minutes. In Period III there were twenty-one intervals of standing, varying from seven to one hundred and eleven minutes each, and twenty intervals of lying, varying from fifty-nine to one hundred and forty-six minutes each. In Period IV there were seventeen intervals of standing, varying from nine to one hundred and seventy-four minutes each, and sixteen intervals of lying, varying from two to one hundred and ninety-two minutes each. In Period V there were sixteen intervals of standing, varying from eleven to one hundred and eighty-six minutes each, and fifteen intervals of lying, ranging from seventy-three to one hundred and seventy-seven minutes each. In Period VI there were fifteen intervals each of standing and lying, the length of the standing intervals varying from seven to one hundred and sixty-six minutes and that of the lying from sixty-eight to one hundred and eighty-two minutes. Few of the intervals of either standing or lying, however, were less than ten minutes, the exception being eight in Period I, standing; seven in Period III, standing; nine in Period IV,

standing; two in Period IV, lying; and seven in Period VI, standing. The average length of the standing and lying intervals was:

	Standing	Lying
Period I	61 minutes	79 minutes
Period II	67 "	102 "
Period III	41 "	102 "
Period IV	64 "	111 "
Period V	61 "	126 "
Period VI	72 "	120 "

In addition to the separate determinations during the intervals of standing and lying, the total excretion of carbon dioxide and water vapor during each subperiod of twelve hours was also determined in duplicate in the customary way, namely, in a sample taken automatically by the metre pump (intermittent sampling) and in a continuous sample taken by a large aspirator having a capacity of about 800 litres. The results obtained on these two samples and the totals obtained by adding the results for the intervals of standing and lying showed a close agreement in nearly every instance, thus attesting the general accuracy of the work.

For each of the twenty-four twelve-hour subperiods, as well as for the whole of each period, the rate of elimination per minute of water vapor, carbon dioxide, total heat, and heat given off by radiation and conduction were computed from the totals found for the corresponding intervals. From these data the percentage increase observed in the standing over the lying periods was computed with the results shown in Table I.

It is clear that in general the increased emission of heat in the intervals of standing was accompanied by a correspondingly increased elimination of both carbon dioxide and water vapor, the parallelism being, on the whole, quite close, although with a tendency to a greater increase in the heat than in the carbon dioxide, which in a few instances, especially in Periods IV and VI, is somewhat marked. The same thing is shown in a different way by computing the heat emission per gram of carbon dioxide excreted as in Table II. We conclude, therefore, that the increased heat *emission* by cattle during standing, which has been invariably observed in our experiments, represents substantially the increase in heat *production* during the same time.

TABLE I.

PERCENTAGE INCREASE IN STANDING OVER LYING.

Period.	Position.	Subperiod 1.	Subperiod 2.	Subperiod 3.	Subperiod 4.	Whole period.
Period I	Carbon dioxide	32.9	25.4	26.2	26.8	27.4
	Water vapor	27.6	31.1	21.0	43.9	30.3
	Total heat	33.2	31.8	34.5	29.3	32.3
	Radiated heat	35.1	32.1	39.1	25.2	32.9
Period II	Carbon dioxide	32.8	30.7	21.6	28.6	28.2
	Water vapor	31.7	28.9	33.8	39.0	31.0
	Total heat	31.5	27.2	32.3	43.3	33.7
	Radiated heat	31.4	26.6	35.2	44.8	34.6
Period III	Carbon dioxide	35.1	33.1	39.8	34.6	35.1
	Water vapor	33.5	35.4	33.9	38.5	34.6
	Total heat	35.3	35.1	38.3	39.5	36.8
	Radiated heat	35.9	35.0	39.5	39.7	37.5
Period IV	Carbon dioxide	18.5	17.4	30.7	17.5	20.4
	Water vapor	30.2	28.0	28.7	31.0	28.4
	Total heat	38.8	34.6	30.9	34.1	34.0
	Radiated heat	41.4	36.6	31.6	35.0	35.7
Period V	Carbon dioxide	33.8	32.8	30.2	30.9	31.6
	Water vapor	25.4	48.9	29.6	42.3	34.6
	Total heat	33.5	44.2	38.8	39.5	38.4
	Radiated heat	35.8	43.0	41.1	38.8	39.4
Period VI	Carbon dioxide	36.5	12.4	28.5	20.5	24.0
	Water vapor	34.2	38.7	46.1	50.6	42.3
	Total heat	30.2	45.5	36.1	48.4	40.0
	Radiated heat	29.2	47.3	33.7	47.9	39.4

It will be noted that the influence of standing and lying upon the excretion of carbon dioxide was very much greater in these experiments than was observed by Hagemann or by Dahm. We are unable at present, however, to suggest any explanation of this difference, although it should be remembered that their results relate only to the

TABLE II.
TOTAL HEAT PER GRAM CARBON DIOXID.

Period.	Position.	Subperiod 1.	Subperiod 2.	Subperiod 3.	Subperiod 4.	Whole period.
Period I	Standing	2.400	2.399	2.453	2.218	2.373
	Lying	2.396	2.282	2.301	2.175	2.285
Period II	Standing	2.408	2.266	2.569	2.451	2.426
	Lying	2.431	2.330	2.361	2.200	2.327
Period III	Standing	2.390	2.295	2.451	2.451	2.402
	Lying	2.385	2.261	2.480	2.365	2.372
Period IV	Standing	2.595	2.603	2.402	2.669	2.572
	Lying	2.216	2.270	2.398	2.338	2.310
Period V	Standing	2.580	2.701	2.619	2.615	2.626
	Lying	2.584	2.488	2.455	2.454	2.498
Period VI	Standing	2.441	2.908	2.601	2.816	2.695
	Lying	2.559	2.247	2.455	2.286	2.387

respiratory excretion, while ours include also the cutaneous excretion and the carbon dioxide produced in the fermentations taking place in the alimentary canal.

That the calorific equivalent of carbon dioxide is in most cases materially lower than that corresponding to either protein, fats, or carbohydrates is doubtless to be ascribed to the very low thermal equivalent of the considerable amount of carbon dioxide produced in the methane fermentation, estimated by Zuntz¹⁶ at 0.5 cal. per litre, equal to 0.253 cal. per gram.

¹⁶ ZUNTZ: Jahrbuch des Vereins der Spiritusfabrikanten in Deutschland, 1912, xii, p. 328.

Influence of Standing or Lying upon Metabolism of Cattle. 253

Finally, the computation, in Table III, of the percentage of the total heat which was given off as latent heat of water vapor shows

TABLE III.
PERCENTAGE OF HEAT GIVEN OFF IN WATER VAPOR.

Period	Position.	Subperiod 1.	Subperiod 2.	Subperiod 3.	Subperiod 4.	Whole period.
Period I	Standing	24.60	23.31	22.91	24.42	23.73
	Lying	25.66	23.44	25.46	21.95	24.10
Period II	Standing	24.50	23.33	23.83	25.56	24.31
	Lying	24.47	23.01	25.47	26.34	24.82
Period III	Standing	22.98	22.52	22.82	21.81	22.48
	Lying	23.29	22.48	33.36	21.96	22.86
Period IV	Standing	22.08	21.69	24.07	22.29	22.46
	Lying	23.53	22.80	24.46	22.80	23.44
Period V	Standing	20.26	20.96	18.74	20.01	19.88
	Lying	21.58	20.31	20.07	19.61	20.44
Period VI	Standing	21.40	20.49	20.89	20.72	20.85
	Lying	20.78	21.50	19.46	20.42	20.52

that this relation also was remarkably uniform, and fully justifies the assumption previously mentioned upon which we have based the computation of our earlier results.

REPRINTED FROM
ORIGINAL COMMUNICATIONS, EIGHTH INTERNATIONAL
CONGRESS OF APPLIED CHEMISTRY. Vol. XV—Page 23.

*(Investigations at the Institute of Animal Nutrition of The
Pennsylvania State College in co-operation with the Bureau of
Animal Industry of the United States Department of Agriculture.)*

THE INFLUENCE OF STANDING OR LYING UPON THE METABOLISM OF CATTLE

BY HENRY PRENTISS ARMSBY AND J. AUGUST FRIES

State College, Pa.

In a number of previous publications,¹ we have called attention to the very marked increase in the total metabolism of cattle in the standing as compared with the lying position which has been uniformly observed in our experiments. In thirty-seven published experiments, this increase varied from a minimum of 28.3 per cent. to a maximum of 64.5 per cent., averaging 41.4 per cent. and a considerable number of unpublished experiments have given entirely similar results. The foregoing figures refer primarily to that portion of the total heat which was given off by radiation and conduction and do not include that eliminated by means of the evaporation of water. On various grounds, however,² it was assumed in discussing the experimental results that the proportion of the total heat produced which was carried off as latent heat of water vapor was essentially the same in the standing and lying positions, and the results of the experiments were computed upon the basis of this assumption.

Such an increase in metabolism as a result of standing is quite in accord with the results of numerous previous investigations, especially upon man. Thus Katzenstein³ in experiments upon himself observed an increase in the oxygen consumption varying from a maximum of 32 per cent. to practically zero when standing

¹U. S. Dept. Agr., Bureau of Animal Industry, Bulletins No. 51 (1903), p. 35; No. 74 (1905), p. 21; No. 101 (1908), p. 20; No. 128 (1911), p. 42.

²Compare especially U. S. Dept. Agr., Bureau of Animal Industry, Bulletin No. 128, pp. 122-124.

³Arch. Physiol. (Pflüger), 49 (1891), 361-362.

with the least possible muscular exertion. Zuntz¹ in experiments on a dog observed an increase of 40.9 per cent. in the oxygen consumption and one of 36.5 per cent. in the carbon dioxide excretion in the standing as compared with the lying position. Bornstein and Ott² in experiments on themselves found an increase of 6.6 Cals. and 11.8 Cals. per hour, respectively, in the computed heat production when standing over that when lying. Widlund,³ on the other hand, obtained but a slight increase in the carbon dioxide excretion in standing as compared with lying. Benedict and Carpenter,⁴ as the average of a number of experiments comparing sitting with standing, find an increase in the latter of 12 per cent. for carbon dioxide, 16 per cent. for oxygen and 17 per cent. for heat production.

Quite recently, however, Zuntz⁵ has called attention to the apparently small influence of standing and lying upon the metabolism of the sheep, as computed from experiments by Hagemann⁶ in which the difference in the heat production as computed from the respiratory exchange was only 8 per cent. Dahm,⁷ working in Zuntz's laboratory and by his methods, likewise found an increase of only 8 per cent. in the respiratory excretion of carbon dioxide by a young bull when standing as compared with that when lying. Zuntz points out that even with a uniform rate of heat production the heat emission would tend to be less in the lying posture, since less of the animal's surface is exposed for radiation and evaporation, and is inclined to attribute the discrepancy between our results and those of Hagemann and of Dahm to this effect. In other words, Zuntz believes that the differences in the heat emission observed in our experiments are much exaggerated by a storing up of heat, during the intervals of lying, in the platform upon which the animal rests or in the body of the animal itself, this heat being given off again in the succeeding intervals of standing.

¹Arch. Physiol. (Pflüger), **68** (1897), 194-5.

²Arch. Physiol. (Pflüger), **109** (1905), 621.

³Skand. Arch. Physiol., **17** (1905), 290.

⁴Carnegie Institution of Washington, Publication 126 (1910), pp. 243-253.

⁵Medizinische Klinik, 1910.

⁶Arch. (Anat. u.) Physiol., 1899, Suppl. p. 111.

⁷Biochem. Ztschr., **28**, 494.

That there must be a tendency in this direction is undeniable, but we have not believed the effect to be of sufficient magnitude to seriously affect our comparisons of the metabolism in the two positions. There must necessarily be a limit to the amount of heat which can be stored up in the platform in this way and it is easy to find in our experiments comparatively long intervals of lying in which, if Zuntz's explanation of the results be accepted, there must have been a storage in the platform of two or three times as much heat as it can be computed to have retained even upon the most extreme assumptions. Moreover, such an accumulation of heat in the platform would necessarily tend to increase radiation from the latter so that the heat emission during lying should tend to increase until it reached the level of the actual production by the animal. As a matter of fact, we have failed to find any distinct tendency of this sort in our experiments. Indeed, the heat emission during the periods of lying tends to be very uniform—more so, in fact, than during the periods of standing.

Obviously, however, arguments like the foregoing cannot be conclusive and it still appeared that in comparisons between shorter intervals of standing and lying the difference in the heat emission as measured might be considerably greater than that indicated by a comparison of the gaseous exchange. In order to test this, appliances have been devised which permit the separate determination of the carbon dioxide and water vapor excreted in the intervals of standing and lying, respectively, and the present paper is a preliminary report upon the results obtained.

The experiments were made with the respiration calorimeter of the Institute which is a modification of the original Atwater-Rosa apparatus for experiments on man.¹ The apparatus is essentially a respiration apparatus of the Pettenkofer type with the addition of appliances for the determination of the heat emitted by the animal under experiment. A general description of the apparatus has been more than once given,² and a recent

¹U. S. Dept. Agr., Office of Experiment Stations, Bulletin No. 63 (1899).

²U. S. Dept. Agr., Bureau of Animal Industry, Bulletin No. 51 (1903); Experiment Station Record, **15** (1903-4), 1037; Bureau of Animal Industry, Twenty-third Annual Report (1906).

publication¹ describes in considerable detail the experimental methods pursued in these investigations. Repeated check tests in which pure alcohol was burned in the apparatus have shown that the results obtained may be regarded as accurate within the following percentages of the total amounts determined.

Carbon dioxid, 0.5 per cent.

Water vapor, 6.0 per cent.

Heat, 1.0 per cent.

For the special determinations of carbon dioxid and water vapor here reported, samples of both the ingoing and outcoming air are taken by means of rotary blowers. Each sample passes through an absorption train in which the carbon dioxid and water are absorbed and weighed, then through the blower, which is immersed in an oil bath, and finally through a calibrated meter (made by the Daansk Maalerfabrik, Copenhagen) which records the volume of the sample. By means of a series of valves coupled together the two currents of air may, at the instant when the animal stands up, be shunted from one absorption train and meter to another, while when he lies down again the current may be shunted back to the first series. In this way the aggregate excretion of carbon dioxid and water vapor for the experimental period in the two positions is determined. At each change of position, samples of the air in the chamber of the apparatus are also taken for determination of the residual carbon dioxid and water vapor.

The three experiments upon a steer here reported form part of a series upon alfalfa hay and the so-called "alfalfa meal" (finely ground alfalfa hay). Each experiment extended over 48 consecutive hours (exclusive of 5 or 6 preliminary hours), covering the eighteenth and nineteenth days of a twenty-one day feeding period, and was divided into four subperiods of 12 hours each, the results for which are given separately. The rations consumed were:

Period II, 7.5 Kgs. alfalfa meal.

Period III, 6.0 Kgs. alfalfa hay.

Period V, 3.5 Kgs. alfalfa hay.

¹U. S. Dept. Agr., Bureau of Animal Industry, Bulletin No. 128 (1911), pp. 200-222.

TABLE I. Total excretion of water vapor and carbon dioxid.

	Subperiod 1		Subperiod 2		Subperiod 3		Subperiod 4	
	H ₂ O Grams	CO ₂ Grams	H ₂ O Grams	CO ₂ Grams	H ₂ O Grams	CO ₂ Grams	H ₂ O Grams	CO ₂ Grams
<i>Period II</i>								
Sampled by pump	2251.04	2239.75	2062.28	2267.46	2373.64	2315.53	2355.03	2294.06
Sampled by aspirator	2271.92	2285.94	2078.37	2307.36	2389.89	2337.46	2358.88	2309.87
Sum of standing and lying	2295.61	2274.27	2061.56	2271.19	2410.29	2333.28	2374.22	2323.73
Total	6818.57	6799.96	6202.21	6846.01	7173.82	6986.27	7088.13	6927.66
Average	2272.86	2266.65	2067.40	2282.00	2391.27	2328.76	2362.71	2309.22
<i>Period III</i>								
Sampled by pump	1921.56	1999.09	1786.38	2003.38	1944.90	2005.47	1792.07	2015.43
Sampled by aspirator	1882.01	1997.01	1787.33	2053.65	2022.55	2061.69	1816.74	2026.87
Sum of standing and lying	1885.66	2014.93	1786.65	2062.29	2023.48	2069.51	1791.51	2009.42
Total	5689.23	6011.03	5360.36	6124.32	5990.93	6136.67	5400.32	6051.72
Average	1896.41	2003.68	1786.79	2041.44	1996.98	2045.56	1800.11	2017.24
<i>Period V</i>								
Sampled by pump	1291.47	1429.42	1301.31	1420.96	1299.48	1419.60	1151.66	1374.69
Sampled by aspirator	1269.37	1410.98	1264.89	1424.91	1219.29	1458.28	1206.29	1412.11
Sum of standing and lying	1296.25	1395.68	1280.22	1427.63	1220.51	1456.87	1227.34	1443.20
Total	3857.09	4236.08	3846.42	4273.50	3739.28	4334.75	3585.29	4230.00
Average	1285.70	1412.03	1282.14	1424.50	1246.43	1444.92	1195.10	1410.00

TABLE II. Metabolism of a Steer, Standing and Lying.

	Subperiod 1		Subperiod 2		Subperiod 3		Subperiod 4		Totals	
	Standing	Lying	Standing	Lying	Standing	Lying	Standing	Lying	Standing	Lying
<i>Period II</i>										
Minutes	302.0	418.0	271.0	449.0	301.0	419.0	265.2	454.8	1139.2	1740.8
Water vapor										
Total, grams	1119.21	1176.40	902.30	1159.26	1134.54	1275.75	1062.97	1311.25	4219.02	4922.66
Per minute, grams	3.7060	2.8144	3.3293	2.5819	3.7692	3.0447	4.0082	2.8831	3.7035	2.8278
Carbon dioxide										
Total, grams	1113.45	1160.82	1001.78	1269.41	1087.81	1245.47	995.86	1327.87	4198.90	5003.57
Per minute, grams	3.6869	2.7771	3.6966	2.8272	3.6140	2.9725	3.7551	2.9197	3.6858	2.8743
Heat										
Total										
Radiated, cal.	2024.39	2132.02	1740.82	2277.93	2129.12	2191.63	1817.28	2152.16	7711.61	8753.74
Latent in H ₂ O, cal.	656.98	690.55	529.65	680.49	665.97	748.87	623.96	769.70	2476.56	2839.61
Sum, cal.	2681.37	2822.57	2270.47	2958.42	2795.09	2940.50	2441.24	2921.86	10188.17	11643.35
Per minute										
Radiated, cal.	6.7033	5.1005	6.4237	5.0733	7.0735	5.2306	6.8525	4.7321	6.7693	5.0286
Latent in H ₂ O, cal.	2.1754	1.6521	1.9544	1.5158	2.2125	1.7872	2.3528	1.6924	2.1739	1.6599
Sum, cal.	8.8787	6.7516	8.3781	6.5891	9.2860	7.0178	9.2053	6.4245	8.9433	6.6885
<i>Period III</i>										
Minutes	204.5	515.5	183.5	536.5	194.3	525.7	263.5	456.5	845.8	2034.2
Water vapor										
Total, grams	631.74	1230.27	565.61	1221.72	609.57	1352.98	807.10	1009.64	2694.02	4814.61
Per minute, grams	3.1870	2.3866	3.0823	2.2772	3.4461	2.5737	3.0630	2.2117	3.1852	2.3608
Carbon dioxide										
Total, grams	696.79	1300.22	642.38	1411.27	702.50	1359.19	886.04	1140.83	2927.71	5211.51
Per minute, grams	3.4073	2.5223	3.5007	2.6305	3.6155	2.5855	3.3626	2.4991	3.4615	2.5619

	Subperiod 1		Subperiod 2		Subperiod 3		Subperiod 4		Totals	
	Standing	Lying	Standing	Lying	Standing	Lying	Standing	Lying	Standing	Lying
<i>Period IV</i>										
Minutes	1282.51	2379.26	1142.31	2473.44	1329.16	2577.04	1698.49	2105.60	5452.47	9535.34
Water vapor										
Total, grams	382.57	722.17	332.01	717.15	393.04	794.20	473.77	592.66	1581.39	2826.18
Per minute, grams	1665.08	3101.43	1474.32	3190.59	1722.20	3371.24	2172.26	2698.26	7033.86	12361.52
Carbon dioxide										
Total, grams	6.2714	4.6154	6.2251	4.6103	6.8408	4.9021	6.4459	4.6125	6.4465	4.6875
Per minute, grams	1.8708	1.4009	1.8093	1.3367	2.0229	1.5108	1.7980	1.2983	1.8697	1.3893
Sum, cal.	8.1422	6.0163	8.0344	5.9470	8.8637	6.4129	8.2439	5.9108	8.3162	6.0769
<i>Period V</i>										
Minutes	215.5	504.5	206.6	513.4	308.8	411.2	239.8	460.2	990.7	1889.3
Water vapor										
Total, grams	449.93	846.32	77.04	803.18	599.43	621.08	544.13	683.21	2070.53	2953.79
Per minute, grams	2.0878	1.6775	2.3090	1.5644	1.9412	1.5104	2.0944	1.4846	2.0900	1.5634
Carbon dioxide										
Total, grams	504.94	890.74	494.55	933.08	717.07	739.80	610.32	832.88	2326.88	3396.50
Per minute, grams	2.3431	1.7656	2.3938	1.8175	2.3221	1.7991	2.3492	1.8098	2.3487	1.7978
Heat										
Total										
Radiated, cal.	1061.80	1830.30	1058.34	1838.40	1530.07	1443.58	1280.08	1634.00	4930.29	6746.28
Latent in H ₂ O, cal.	264.11	496.79	280.02	471.47	351.87	364.57	319.40	401.04	1215.40	1733.87
Sum, cal.	1325.91	2327.09	1338.36	2309.87	1881.94	1808.15	1599.48	2035.04	6145.69	8480.15
Per minute										
Radiated, cal.	4.9271	3.6279	5.1227	3.5808	4.9549	3.5107	4.9272	3.5506	4.9766	3.5708
Latent in H ₂ O, cal.	1.2256	0.9847	1.3534	0.9183	1.1395	0.8866	1.2294	0.8714	1.2268	0.9177
Sum, cal.	6.1527	4.6127	6.4780	4.4992	6.0944	4.3973	6.1566	4.4221	6.2034	4.4885

The ration of Period III was estimated to be approximately a maintenance ration. The subject was a pure-bred shorthorn steer about twenty months old, in moderate condition, and weighing about 360 Kgs.

The total excretion of carbon dioxide and water vapor during each subperiod of 12 hours was determined in duplicate, viz., in a sample taken automatically by the meter pump (intermittent sampling) and in a continuous sample taken by a large aspirator having a capacity of about 800 liters. In Table I the results obtained on these two samples are compared with the totals obtained by adding the results for the intervals of standing and lying. The close agreement of the three attests the general accuracy of the work.

The partition of water vapor, carbon dioxide and heat eliminated between the intervals of standing and of lying during each subperiod and for the entire forty-eight hours was as shown in Table II. In Period II there were seventeen intervals each of standing and lying, the length of the standing intervals varying from 2 to 147 minutes and that of the lying intervals from 20 to 145 minutes. In Period III there were twenty-one intervals of standing, varying from 4 to 111 minutes each and twenty intervals of lying varying from 9 to 142 minutes each. In Period V there were 16 intervals of standing, varying from 11 minutes to 186 minutes each and fifteen intervals of lying, ranging from 72 minutes to 177 minutes each. Few of the intervals of either standing or lying, however, were less than 10 minutes, the exception being, 2 in Period II, standing, 4 in Period III, standing, and 1 in Period III, lying. The average length of the standing and lying intervals was

	Period II	Period III	Period V
Standing	67 minutes	40 minutes	62 minutes
Lying	102 "	102 "	126 "

These rather frequent changes of posture on the part of the animal would tend to emphasize any effect of a storing up of heat in the platform upon the partition of the heat emission between the standing and lying intervals.

From the data contained in Table II, the percentage increase observed in the standing over the lying periods may be computed with the results shown in Table III.

TABLE III.—Percentage Increase in Standing over Lying.

	Subperiod 1	Subperiod 2	Subperiod 3	Subperiod 4	Whole period
<i>Period II</i>					
Carbon dioxide	32.8	30.7	21.6	28.6	28.2
Water vapor	31.7	28.9	23.8	39.0	31.0
Total heat	31.5	27.2	32.3	43.3	33.7
Radiated heat	31.4	26.6	35.2	44.3	34.6
<i>Period III</i>					
Carbon dioxide	35.1	33.1	39.8	34.6	35.1
Water vapor	33.5	35.4	33.9	38.5	34.6
Total heat	35.3	35.1	38.2	39.5	36.8
Radiated heat	35.9	35.0	39.5	39.7	37.5
<i>Period V</i>					
Carbon dioxide	32.7	31.7	29.1	29.8	30.6
Water vapor	24.5	47.6	28.5	41.1	33.7
Total heat	33.4	44.0	38.6	39.2	38.2
Radiated heat	35.8	43.0	41.1	38.8	39.4

It is clear that the increase emission of heat in the intervals of standing was accompanied by a correspondingly increased elimination of both carbon dioxide and water vapor, the parallelism being quite close although with a tendency to a greater increase in the heat than in the carbon dioxide which in a few instances is somewhat marked. The same thing is shown in a different way by computing the heat emission per gram of carbon dioxide excreted as in Table IV. We conclude, therefore, that the increased heat emission by cattle during standing, which has been invariably observed in our experiments, represents substantially the increase in heat production during the same time.

It will be noted that the influence of standing and lying upon the excretion of carbon dioxide was very much greater in these experiments than was observed by Hagemann or by Dahm. We are unable at present, however, to suggest any explanation of this difference.

That the calorific equivalent of carbon dioxide is in most cases materially lower than that corresponding to either protein, fats, or carbohydrates is doubtless to be ascribed to the very low thermal equivalent of the considerable amount of carbon dioxide produced in the methan fermentation, estimated by Zuntz¹ at 0.5 Cal. per liter, equal to 0.253 Cal. per gram.

TABLE IV—Total Heat per Gram Carbon Dioxide.

	Subperiod 1	Subperiod 2	Subperiod 3	Subperiod 4	Whole period
<i>Period II</i>					
Standing	2.408	2.266	2.569	2.451	2.426
Lying	2.431	2.330	2.361	2.200	2.327
<i>Period III</i>					
Standing	2.390	2.295	2.451	2.451	2.402
Lying	2.385	2.261	2.480	2.365	2.372
<i>Period V</i>					
Standing	2.626	2.706	2.625	2.621	2.641
Lying	2.613	2.476	2.444	2.444	2.497

Finally, the computation, in Table V, of the percentage of the total heat which was given off as latent heat of water vapor shows that this relation also was remarkably uniform and fully justifies the assumption previously mentioned upon which we have based the computation of our earlier results.

¹Jahrbuch des Vereins der Spiritusfabrikanten in Deutschland, 12, (1912) 328.

TABLE V—Percentage of Heat Given off in Water Vapor.

	Subperiod 1	Subperiod 2	Subperiod 3	Subperiod 4	Whole period
<i>Period II</i>					
Standing	24.50	23.33	23.83	25.56	24.31
Lying	24.47	23.01	25.47	26.34	24.82
<i>Period III</i>					
Standing	22.98	22.52	22.82	21.81	22.48
Lying	23.29	22.48	23.56	21.96	22.86
<i>Period V</i>					
Standing	19.93	20.92	18.70	19.97	19.78
Lying	21.35	20.41	20.16	19.71	20.45

THE COMBUSTIBLE GASES EXCRETED BY CATTLE

By J. AUGUST FRIES

State College, Pa.

Several years ago the writer¹ called attention to the composition and quantity of the combustible gases excreted by cattle as affected by variations in the quantity of timothy hay consumed. During four experimental periods the daily ratio of hydrogen to carbon in the combustible gases ranged from 1:2.899 to 1:3.096 with an average of 1:2.967, which is practically identical with the ratio of carbon to hydrogen in methan. Since that time many nutrition experiments upon steers have been carried on by the aid of the respiration calorimeter under the direction of Dr. H. P. Armsby at the Institute of Animal Nutrition of The Pennsylvania State College, in all of which the carbon and hydrogen of the combustible gases excreted by the animals have been determined.

APPARATUS AND METHODS

As related to the experiments here reported, the respiration calorimeter is substantially a Pettenkofer respiration apparatus, the ventilation being maintained and measured by means of a pump which also takes automatically duplicate analysis samples of $\frac{1}{200}$ of the total ventilation. One of these samples, after passing through an absorbent train which takes up the H_2O and CO_2 , passes over platinized kaolin at a dull red heat, the H_2O and CO_2 formed being absorbed in a second train of U tubes. The sampling by the meter pump is intermittent but for the twelve-hour subperiods of these experiments it has been shown to be accurate.

During Periods IV and V with Steer D and Periods III, IV and V with Steer G, Experiment No. 211, an electric furnace²

¹Proceedings of the Twenty-third Annual Meeting of the Society for the Promotion of Agricultural Science (1902), p. 110.

²Jour. Amer. Chem. Soc., Vol. XXXII, No. 8 (1910).

was used, but previous to that the combustion tube was heated by gas. The combustion tube is a long copper tube 2.5 c.m. inside diameter filled with lumps of platinized kaolin and heated to dull redness, about 700° C., over a length of 2.1 meters. The combustion furnaces and tubes were tested by burning known quantities of ethyl alcohol vapor and determining the H₂O and CO₂ produced. The following tests, Table I, show that the oxidation of the vapor was complete. The CO₂ found agrees closely with the theoretical, but the water was probably not driven completely from the connections where it had condensed.

TABLE I

Date		C ₂ H ₅ O Gms.	Hours	H ₂ O Gms.	CO ₂ Gms.	
Oct. 4, 1906	Gas furnace	4.0566	4	5.1955 5.2429	7.7570 7.7521	Found Theoretical
Mar. 3, 1910	Electric furnace	4.8192	3	6.1812 6.2497	9.2150 9.2093	Found Theoretical

CHECK TESTS

Blank tests:—It was not possible to make parallel determinations of the combustible gases in the ingoing air and hence blank tests were made from time to time in order to obtain corrections for the apparatus and the outside air. These blank determinations were not made at, or necessarily near, the time of the individual respiration experiments. They represent rather the average condition of the ingoing air and the combustion furnace, and since the analytical error is relatively large, on account of the large apparatus used and the small total quantity of hydrogen and carbon found, the average result of all the tests is used.

Table II gives the average of 22 blank tests which represent many different climatic conditions during a number of years.

Between the individual blank determinations there is considerable variation, yet the total correction is not very large. The ratio of hydrogen to carbon is 1:0.682, so that when the carbon

is computed to methane, there is an excess of free hydrogen equivalent to 0.001475 gram or 16.38 c.c. in 1000 liters air at 0° and 760 m.m.

TABLE II—Blank Tests of Outside Air

Combustible hydrogen and carbon weighed as water and carbon dioxide

Year	Number of single determinations	Average results		
		Air sample at 0° & 760 m.m. Liters	In 1000 liters air H ₂ O Gram	CO ₂ Gram
1903	5	1078.18	.021754	.005937
1904	3	940.67	.017142	.008206*
1905	6	1349.97	.017924	.004510
1906	3	1899.60	.011989	.003202
1907	3	1558.37	.013689	.004618*
1910	2	1800.00	.017143	.001911
	Average of all determinations	1376.66	.017230	.004790

*Average of two determinations only.

Alcohol check tests:—These alcohol check tests, by which the efficiency and reliability of the respiration calorimeter as a whole is tested, also serve as a check on the combustible hydrogen obtained in the blank tests. With the exception of probably less than 1 per cent. of the total ventilation which comes in close contact with the flame, in an alcohol check test all gases from without must pass through the chamber unchanged. Hence the combustible hydrogen obtained during such a test is a maximum above which the blank tests should not go. In Table III is given the average result as regards combustible gases of 20 alcohol check tests; and, leaving out one of the water determinations in 1902 which gave a high result in water without a corresponding increase in carbon dioxide, the average of the 19

determinations would be .017800 gram water in 1000 liters, a close agreement with the average of the blank tests.

TABLE III—Combustible Gases Found in Alcohol Check Tests

Hydrogen and carbon weighed as water and carbon dioxid

Year	Number of single determinations	Average Results			
		Air sample at 0° & 760 m.m. Liters	Pure ethyl alcohol burned Grams	In 1000 liters air	
				H ₂ O Gram	CO ₂ Gram
1902	3	1432.65	641.62	.020999	.030718
1903	3	1035.82	467.92	.023583	.021791
1904	3	1074.15	459.54	.020609	.023660
1905	1	1977.74	843.73	.017393	.014562
1906	2	1601.56	649.64	.012411	.018419
1907	4	1567.46	641.52	.015935	.015768
1908	2	1551.47	603.14	.018259	.012453
1909	2	1521.95	588.38	.017758	.012225
	Average of all determinations	1411.27	589.97	.018678	.019582

RECORD OF EXPERIMENTS

In Table IV are given the results obtained in 57 respiration calorimeter experiments with various steers and feeds, carried on between the years 1903 and 1911, showing the average combustible hydrogen and carbon excreted per day in each period, corrected for blank, and the ration of hydrogen to carbon. Further, there is given the combustible carbon per kilogram dry matter eaten and the combustible carbon in per cent. of the total gaseous carbon excreted as carbon dioxid. The experiments with the same kind of feed are grouped together and the periods for each animal arranged in order of the amount of feed eaten so as to facilitate the study of the results.

TABLE IV. Excretion of Combustible Gases by Steers Weighed as Water and Carbon Dioxid

Steer	Average live weight Kgs.	Experiment number	Period	Dry matter eaten Grams	Total combustible		Ratio H : C	Carbon per Kg. dry matter eaten Grams	Carbon in p. c. of total gaseous carbon as carbon dioxide
					Hydrogen Grams	Carbon Grams			
R	520	179	II	3143.0	17.751	57.485	1:3.238	18.290	5.726
	544	179	I	4459.0	24.895	77.506	1:3.113	17.382	6.532
	561	186	I	2933.3	15.691	50.473	1:3.217	17.207	4.649
	566	186	III	4139.1	18.900	59.731	1:3.160	14.430	4.774
	572	186	II	5025.3	19.537	61.652	1:3.155	12.267	5.395
							1:3.176		
	CLOVER HAY								
R	514	179	III	{ 3162.8 734.7	25.236	77.951	1:3.089	20.000	7.061
	531	179	IV	{ 3186.4 3450.8	44.858	137.212	1:3.059	20.672	10.771
							1:3.075		
	CLOVER HAY AND MAIZE MEAL								
A	269	190	III	2001.0	10.953	35.127	1:3.207	17.512	5.788
	277	190	IV	3493.0	20.062	59.728	1:2.982	17.100	7.535
	507	207	III	2974.0	19.337	61.092	1:3.159	20.542	7.238
	514	207	IV	4892.0	31.317	97.597	1:3.116	19.950	8.826
B	194	190	III	1774.0	10.651	34.489	1:3.238	19.440	6.639
	190	190	IV	2610.0	14.563	44.855	1:3.080	17.185	7.500
	374	207	III	2798.0	18.696	58.915	1:3.151	21.055	7.036
	385	207	IV	4030.0	29.581	91.734	1:3.101	22.762	8.551
							1:3.142		
	TIMOTHY HAY								

Steer	Average live weight Kgs.	Experiment number	Period	Dry matter eaten Grams	Total combustible		Ratio H : C	Carbon per Kg. dry matter eaten Grams	Carbon in p. c. of total gaseous carbon as carbon dioxide
					Hydrogen Grams	Carbon Grams			
TIMOTHY HAY AND WHEAT BRAN									
A	271	190	I	{ 1977.8 1370.2	20.464	62.474	1:3.053	18.660	7.158
	279	190	II	{ 1995.8 2583.2	25.480	79.715	1:3.128 1:3.090	17.407	7.856
B	199	190	I	{ 1770.5 1032.5	16.069	49.759	1:3.096	17.752	7.046
	197	190	II	{ 1779.4 1802.6	22.050	66.601	1:3.020 1:3.058	18.592	8.447
TIMOTHY HAY AND MIXT GRAIN*									
A	499	207	I	{ 2934.8 1996.2	33.222	103.320	1:3.110	20.952	8.702
	519	207	II	{ 2949.0 4759.0	49.152	150.697	1:3.066 1:3.088	19.550	8.817
B	373	207	I	{ 2759.2 1397.8	28.978	89.988	1:3.105	21.647	5.142
	386	207	II	{ 2774.1 2676.9	38.183	117.327	1:3.073 1:3.089	21.522	8.782
ALFALFA HAY									
D	162	208	II	1299.7	5.445	19.477	1:3.577	14.985	4.876
	171	208	I	2154.9	9.254	31.440	1:3.397 1:3.487	14.587	5.941
C	285	208	V	3098.5	14.332	46.472	1:3.243	14.997	6.238
	287	208	IV	4743.9	17.777	56.542	1:3.181 1:3.212	11.917	5.803
E	197	208	VI	1412.9	6.415	21.904	1:3.414	15.502	4.830
	214	208	V	2408.0	11.456	36.935	1:3.224	15.337	6.184
	223	208	IV	4170.2	17.662	55.970	1:3.169	13.420	6.676

Applied Chemistry

1113

Steer	Average live weight Kgs.	Experiment number	Period	Dry matter eaten Grams	Total combustible		Ratio H : C	Carbon per Kg. dry matter eaten Grams	Carbon in p. c. of total gaseous carbon as carbon dioxide
					Hydrogen Grams	Carbon Grams			
F				ALFALFA HAY					
							1:3.269		
	291	209	VI	2226.4	10.660	34.707	1:3.256	15.587	5.141
	310	209	V	3562.2	16.488	52.266	1:3.170	14.672	6.577
	321	209	IV	6173.7	27.555	85.542	1:3.104	13.855	7.120
							1:3.177		
C				ALFALFA HAY AND MIXT GRAIN†					
	260	208	III	{ 520.7 1018.3	10.243	34.674	1:3.385	25.030	5.718
	271	208	II	{ 730.6 1453.3	14.666	47.502	1:3.239	21.750	6.490
							1:3.312		
E	197	208	III	{ 386.8 763.8	5.445	20.050	1:3.682	17.425	4.121
	205	208	II	{ 590.1 1162.7	11.138	36.948	1:3.317	21.077	6.363
	209	208	I	{ 1086.3 2221.9	17.830	56.681	1:3.180	17.132	7.099
							1:3.393		
F	283	209	III	{ 536.1 1112.0	9.111	30.817	1:3.382	18.697	4.879
	293	209	II	{ 893.5 1862.0	14.733	46.659	1:3.167	16.932	5.893
	301	209	I	{ 1461.5 3040.6	22.272	68.946	1:3.095	15.312	6.583
							1:3.215		
D				CORN STOVER					
	325	210	III	2562.8	15.937	50.496	1:3.168	19.702	6.818
	340	210	II	3547.4	21.005	66.354	1:3.159	18.705	7.518
	354	210	I	4335.3	25.811	81.140	1:3.144	18.715	7.805
							1:3.157		

Steer	Average live weight	Experiment number	Period	Dry matter eaten	Total combustible		Ratio	Carbon per Kg. dry matter eaten	Carbon in p. c. of total gaseous carbon as carbon dioxide
	Kgs.				Grams	Hydrogen Grams				Carbon Grams	H : C
D G			MIXT HAY (CLOVER AND TIMOTHY)						
	439	211	V	1786.4	10.878	34.487	1:3.170	19.305	4.519
	463	211	IV	3498.3	21.580	64.880	1:3.006	18.546	6.705
	469	211	I	6204.2	32.119	99.148	1:3.087	15.980	7.567
	375	211	V	1607.8	10.459	32.111	1:3.070	19.970	4.848
	395	211	IV	3148.4	18.716	56.254	1:3.006	17.867	6.172
	397	211	I	6092.0	33.309	102.191	1:3.068	16.775	7.776
						1:3.068			
D		MIXT HAY (CLOVER AND TIMOTHY) AND HOMINY CHOP							
	441	211	II	{ 1747.3 1763.7	25.510	79.179	1:3.104	22.550	7.493
	503	211	III	{ 3910.5 3948.8	49.240	149.725	1:3.041	19.057	8.866
							1:3.072		
G		MIXT HAY (CLOVER AND TIMOTHY) AND CORNMEAL							
	367	211	II	{ 790.3 1541.9	18.257	57.861	1:3.169	24.810	6.644
	405	211	III	{ 2383.2 4643.7	47.422	138.604	1:2.923	19.725	8.594
							1:3.046		

*Wheat bran, 1 part; cornmeal, 3 parts; linseed meal, 3 parts.

†Cracked corn, 6 parts; oats (whole), 3 parts; linseed meal, 1 part.

This record shows a great variation in the daily quantities of hydrogen and carbon given off in the form of combustible gases, ranging from 5.445 grams hydrogen and 19.477 grams carbon with Steer D in Period II of Experiment No. 208, to 49.152 grams hydrogen and 150.697 grams carbon with Steer A in Period II of Experiment No. 207. A variation in the ratio of Hydrogen to carbon also appears, the average of all being 1:3.167. Several

other things are brought out in this table to which attention may be called:

1. The amount of combustible gases increases with increase in quantity of feed eaten.
2. The production of combustible carbon is relatively greater with the smaller rations.
3. In per cent. of the total carbon given off in carbon dioxide, the combustible carbon increases with the increase in the rations.
4. The individuality of the animals does not seem to have any marked influence upon the production of combustible gases.
5. A tendency for higher percentage of carbon to hydrogen is noticed with the smaller rations, but this is especially marked in the rations containing alfalfa hay.

Point 1 is clearly illustrated in Table V, which gives the results obtained with two steers on varying amounts of the same kind of feeds.

TABLE V—Daily Combustible Hydrogen and Carbon from two Steers Fed Increasing Quantities of the Same Kind of Feed

Steer	Experiment No.	Alfalfa hay			Hay and grain		
		Dry matter fed Grams	Combustible		Dry matter fed Grams	Combustible	
			Hydrogen Grams	Carbon Grams		Hydrogen Grams	Carbon Grams
E	208	1412.9	6.415	21.904	1150.6	5.445	20.050
"	208	2408.0	11.456	36.935	1752.8	11.138	36.948
"	208	4170.2	17.662	55.970	2183.9	14.666	47.502
F	209	2226.4	10.660	34.707	1648.1	9.111	30.817
"	209	3562.2	16.488	52.266	2755.5	14.733	46.659
"	209	6173.7	27.555	85.542	4502.1	22.272	68.946

Computed per 1000 grams dry matter eaten, the following amounts of combustible carbon were excreted:

Average for the 23 smallest rations = 19,201 grams carbon
 " " " 23 heaviest " = 17.505 " "

Although there is more combustible gaseous carbon produced per unit of dry matter eaten with the smaller rations, the combustible carbon in per cent. of total carbon excreted as carbon dioxid is, as stated in point 3, greater with the larger rations. This is shown if we average the percentages of the smallest and heaviest rations as follows:

	Total carbon given off as carbon dioxid	Combustible gaseous carbon
23 smallest rations	100.00	6.013
23 heaviest "	100.00	7.623

In regard to Point 5, we find that the average ratio of hydrogen to carbon is:

For the 23 lightest rations, 1:3.230
 " " 23 heaviest " 1:3.110

but with the rations containing alfalfa hay, the average ratio of hydrogen to carbon is

for the 7 lightest rations, 1:3.411
 " " 7 heaviest " 1:3.195

This represents such an unusual condition of things that it requires more than a passing notice. The regularity with which these variations in the ratio of hydrogen to carbon occur and the magnitude of them exclude, I think, the possibility of ascribing them to analytical error or to errors in the blank. The greatest difference is found in the case of Experiment No. 208, Steer E, the ration being alfalfa hay and mixed grain. Here the ratio of hydrogen to carbon varies from 1:3.180 with the highest to 1:3.862 with the lightest ration.

To explain these variations by errors in the average for the blank tests would require, either a reduction of the hydrogen of the blank by 73 per cent. or an increase of its carbon by 416 per cent. Errors of this magnitude in the blanks seem beyond the range of possibility. Neither is it possible to ascribe these variations in the ratios to diffusion of gases through the rubber diafram and connections. While it is not easy to explain the excess of carbon over hydrogen found in these experiments, it would seem

that, at least for the present we must tentatively accept the results as found. These results indicate that the bulk of feed, and length of time which it remains in the animal's body, especially in the case of rations containing alfalfa hay, influence the composition of the combustible gases produced.

Earlier investigators arrived at the conclusion that the combustible portion of the fermentation products in cattle was almost exclusively methan. Markoff,¹ however, finds that the composition of the gases contained in the paunch of ruminants varies greatly both as regards carbon dioxid and free hydrogen. Thus 21 gas samples taken directly from the paunch of a goat showed a variation as follows:

CO ₂	14.95% to 54.32%
CH ₄	19.88% to 42.55%
H ₂	0.05% to 4.07%

These samples, each about 15 c. c. were taken once or sometimes twice a day, some in the morning and others in the afternoon. It is, therefore, not admissible to compare the results based on these samples with those of our own experiments which represent the whole day and the total output of gases from paunch and intestines combined. How closely the results obtained with goats are applicable to cattle is still undetermined.

In Markoff's valuable work, it is noteworthy that an addition of sugar to the paunch content either through the feed or directly through the fistula, caused no marked change in the amount of free hydrogen found. Neither was there any marked change in the composition of the gases when large quantities of protein material were added to the feed.

On the other hand, in the case of the fermentation trials with the paunch contents outside the body it was found possible to change almost at will the composition of the gases by the addition of varying quantities of sugar, etc. Thus in 10 samples:

CO ₂	ranged from 17.08% to 87.49%
CH ₄	" " 0.12% to 22.80%
H ₂	" " 0.03% to 20.04%

showing that outside of the animal body the fermentation processes may be reversed so that instead of methan, only hydrogen and carbon dioxid are produced.

¹Biochem. Ztschr., 34 (1911), 211.

A COMPARISON OF THE OBSERVED AND COMPUTED HEAT PRODUCTION OF CATTLE.¹

BY HENRY PRENTISS ARMSBY.
Received September 18, 1913.

The first investigation by modern methods of the long-standing problem of the source of animal heat was that of Rubner.²

The quantities actually determined in Rubner's experiments were the total nitrogen of the excreta, the respiratory carbon dioxide and the heat produced. The carbon of the visible excreta was computed from their nitrogen, and the absence of carbon compounds, other than carbon dioxide, in the respiration was assumed. From the total excretion of carbon and nitrogen, the catabolism of protein and fat was computed, and from the latter the equivalent amount of heat, using Rubner's well-known factors; it being assumed that there was no material catabolism of carbohydrates. In the aggregate of experiments covering 45 days, the actual heat production, as determined by Rubner's form of animal calorimeter, differed from the amount computed from the body catabolism as follows:

	Cals.
Computed heat production.....	17406.0
Observed heat production.....	17349.7
Difference.....	-56.3 = -0.32%

Laulanié³ has reported similar comparisons on several different species, by what appear to have been somewhat less rigorous methods. These likewise show a close agreement, the observed differing from the computed heat production in the aggregate of all the experiments reported in full by +0.31%.

The most extensive investigations on this subject are those of Atwater and Benedict upon men. Their experiments are distinguished by the accuracy of their technic and by the fact that all the factors involved were,

¹ Investigations at the Institute of Animal Nutrition of The Pennsylvania State College, in coöperation with the Bureau of Animal Industry of the U. S. Department of Agriculture.

² *Z. Biol.*, 30, 73 (1894).

³ *Arch. Physiol.*, 1898, 748.

so far as possible, directly determined. In 30 experiments reported up to the year 1902,¹ and in which the Pettenkofer type of respiration apparatus was employed, the aggregate observed heat production differed from that computed by only -0.05%, the observed heat production tending to be slightly greater than the computed value in the experiments in which there was a gain by the body, and slightly less in those in which there was a loss. Subsequent experiments, in which the oxygen consumption of the subject was determined, while not showing such a very close agreement as the earlier ones, nevertheless substantially confirmed them. In eleven experiments by Benedict and Milner,² aggregating 24 days, the observed differed from the computed heat production by +0.6%. In eighteen later experiments by Benedict,³ mostly on fasting individuals, the corresponding difference was -0.7%.

These various investigations have established beyond reasonable doubt that, in the case of carnivora and of man, the same equivalences between chemical energy, heat energy and mechanical energy obtain in the animal body as elsewhere. It is perhaps a justifiable assumption that the same thing is true of the energy transformations in herbivora, but, with the exception of a few experiments by Laulanié on guinea pigs, rabbits and ducks, the investigations just summarized did not include this large class of animals, so important in their relation to the human food supply and its conservation.⁴ For various reasons, therefore, direct investigations upon herbivorous animals, and in particular upon ruminants, appear desirable.

In the first place, while the fundamental nutritive processes may be assumed to be substantially the same in carnivora, omnivora and herbivora, the nature of the feed consumed by the latter introduces a number of possible modifying factors. Thus the carbohydrates include, along with the starches and sugars, numerous other members of the group, belonging both to the C₆ and C₅ series, especially the less soluble hexosans and pentosans. The nitrogenous ingredients of the feed, too, in addition to true protein, include a great variety of other substances whose physiological significance is but partially understood. The relatively insoluble carbohydrates (woody fiber) render the feed of herbivora bulky, requiring a complicated alimentary canal and doubtless an increased measure of digestive work, while the comparatively low digestibility of the feed results in the excretion of correspondingly bulky feces. Very extensive fermentations of the carbohydrates also occur, especially in the capacious first stomach

¹ U. S. Dept. Agr., Office of Experiment Stations, *Bulletins* 109 and 136; *Memoirs Nat. Acad. Sci.*, 8, 1235.

² U. S. Dept. Agr., Office of Experiment Stations, *Bull.* 175, 262.

³ "Influence of Inanition on Metabolism," Carnegie Institution of Washington, *Publication* 77, 512.

⁴ Compare *Popular Science Monthly*, November, 1911, p. 496.

of ruminants, with production of large amounts of carbon dioxide and methane and sometimes of hydrogen. Finally, the excretory products of the urin include hippuric acid, a rather notable proportion of ammonia, and considerable amounts of non-nitrogenous matter of unknown nature. In view of all these differences, an investigation into the sources of animal heat in the herbivora seems not without scientific interest.

In the second place, the economic aspect of the question, already alluded to, is not without importance. Agricultural animals are transformers of chemical energy, storing up portions of it in forms available for man's nutrition. The fundamental laws governing these transformations, therefore, are of material economic significance.

In the third place, while the newer method of comparing the nutritive values of feeding stuffs for farm animals introduced by Kellner—his so-called "starch values," which are essentially energy values—does not, in terms, assume identical energy equivalences within and without the body. Confidence in its results will, nevertheless, depend largely upon whether or not they may be found in accord with the law of the conservation of energy.

Beginning in 1902, there have been made each year at this institute a number of balance experiments on mature or nearly mature cattle (steers), in which the income and outgo of carbon, hydrogen, nitrogen and energy have been determined and the results of which, therefore, permit a comparison of the observed with the computed heat production.

The experiments have been made with an Atwater-Rosa respiration calorimeter of the earlier type, consisting of a Pettenkofer respiration apparatus, the chamber of which constitutes also an animal calorimeter. The more important details of the apparatus have already been described¹ and a somewhat complete account of the experimental methods employed and of the check tests made has also been published.² On the basis of check tests with burning alcohol, the error of a single experiment is estimated at 0.5% for the CO₂ determination, and at 1.0% for the heat measurement.

	Body protein. ³	Body fat. ⁴
Carbon.....	52.54	76.5
Hydrogen.....	7.14	12.0
Nitrogen.....	16.67	..
Sulfur.....	0.52	..
Oxygen.....	23.12	11.5
	100.00	100.0

¹ U. S. Dept. Agr., Bureau of Animal Industry, *Bull.* 51, 23-25; U. S. Dept. Agr. Expt. Sta., *Rec.* 15, 1037 (1903-4); U. S. Dept. Agr., Bureau of Animal Industry, 23d *Annual Report*, pp. 263-270.

² U. S. Dept. Agr., Bureau of Animal Industry, *Bull.* 128, 200-22.

³ Köhler, *Z. physiol. Chem.*, 31, 479 (1900).

⁴ Schulze and Reinecke, *Landw. Vers. Stat.*, 9, 97 (1867).

From the balance of nitrogen and carbon, the gain or loss of protein and fat is computed in the usual manner, using the preceding figures for the composition of body protein and body fat, respectively.

The energy equivalent to the gain or loss is computed by the use of the usual factors, viz., 5.7 cal. per gram of protein and 9.5 cal. per gram of fat. The heat production is computed by subtracting the energy of the gain by the body (or adding the energy of the loss) from the difference between income and outgo of chemical energy, as in the following illustration:

	Cals.	Cals.
Energy of feed.....	.....	22,486
Energy of feces.....	7,359	.....
Energy of urin.....	1,217	.....
Energy of CH ₄	1,848	.....
Energy of brushings.....	123	.....
Total energy of excreta.....	.....	10,547
Energy of gain.....	.....	11,939
		1,699
Computed heat production.....	.....	10,240
Observed heat production.....	.....	10,174

Aside from experimental errors, such a comparison as the foregoing includes certain other sources of error, to which attention should be called.

The computation of the energy equivalent of the gain by the animal assumes that it consists wholly of protein and fat—in other words, that the stock of body glycogen remains unchanged. The experiments were, in every case, begun after the ration in question had been fed for 17 days consecutively. In those cases in which there was a gain it seems safe to assume that, by the end of that time, the glycogen content of the animal had come into approximate equilibrium with the feed supply, and that the gain did actually consist substantially of protein and fat. With sub-maintenance rations, on the other hand, there is to be considered the possibility of a continuous loss of glycogen for some time, in which case the estimates for the energy equivalent of the loss may be too large by an unknown amount.

As regards the determination of the heat actually produced, two sources of error are to be specially noted.

The first is that due to a gain or loss of matter by the body of the animal. In case of a gain, heat actually produced in the body is stored up in it, while in the contrary case heat generated in the body at some previous time is eliminated and measured along with that actually produced. In the experiments here described, the measured heat has been corrected as accurately as possible for these gains or losses, especially for that of water.

The second source of error in the determination of the heat produced is that arising from fluctuations in the body temperature of the experimental animal. It has not been found practicable thus far to take the temperature of the subject while in the calorimeter. No indications of any abnormal conditions, however, were afforded by the rectal temperature taken outside the calorimeter, and since the experiments began and ended at the same hour it has been assumed that the body temperature was the same at both times.¹

Beginning in 1902, there have been made 57 experiments, the results of which have been computed and are available for comparison.² The results, so far as they relate to the subject under discussion, are contained in the following table, which includes all the experiments made up to the close of the year 1909. Each experiment covered 48 hours and was divided into four sub-periods of 12 hours each. The table shows the average results for 24 hours.

OBSERVED AND COMPUTED HEAT PRODUCTION OF CATTLE.

	Gain by animal. Cals.	Heat production in 24 hours.		Difference.	
		Computed. Cals.	Observed. Cals.	Cals.	Per cent.
Steer I, 1902.....	-2,741	9,243	9,215	-28	-0.3
	-807	10,201	10,296	+95	+0.9
	-9	11,116	10,749	-367	-3.4
	+524	11,577	11,493	-84	-0.7
Steer I, 1903.....	-3,409	11,635	11,529	-106	-0.9
	-4,179	10,123	10,123	0	0
	-2,518	10,655	10,540	-115	-1.1
	+3,791	14,181	14,652	+471	+3.2
Steer I, 1904.....	-5,243	11,014	10,911	-103	-0.9
	-5,374	11,185	11,736	+551	+4.7
	-1,339	11,980	11,435	-545	-4.8
	-1,086	11,727	11,318	-409	-3.6
	-2,715	11,274	10,724	-550	-5.1
	-2,770	11,066	10,875	-191	-1.8
Steer A, 1905.....	-1,260	8,047	8,606	+559	+6.5
	+1,117	8,826	9,149	+323	+3.5
	-2,439	5,979	6,196	+217	+3.5
	-1,271	7,285	7,356	+71	+1.0
Steer B, 1905.....	-818	6,379	6,621	+242	+3.6
	+829	6,901	7,327	+426	+5.8
	-1,869	4,825	5,221	+396	+7.6
	-535	5,346	5,434	+88	+1.6

¹ For further details on these two points, compare U. S. Dept. Agr., Bureau of Animal Industry, *Bull.* 128, 111-13.

² The computation of a considerable number of additional experiments has not been entirely completed.

OBSERVED AND COMPUTED HEAT PRODUCTION OF CATTLE—(Continued).

	Gain by animal. Cals.	Heat production in 24 hours.		Difference.	
		Computed. Cals.	Observed. Cals.	Cals.	Per cent.
Steer A, 1906.....	+1,368	9,249	9,339	+90	+1.0
	+4,305	12,882	12,872	-10	-0.1
	-2,510	7,345	7,452	+107	+1.4
	-287	8,165	8,209	+44	+0.5
Steer B, 1906.....	-640	9,053	8,937	-116	-1.3
	+1,133	9,700	9,736	+36	+0.4
	-2,047	6,709	6,928	+219	+3.2
	-438	7,448	7,380	-68	-0.9
Steer A, 1907.....	+1,699	10,240	10,174	-66	-0.6
	+6,341	14,090	14,140	+50	+0.4
	-1,655	7,766	7,773	+7	+0.1
	+628	9,407	9,493	+86	+0.9
Steer B, 1907.....	-166	9,490	9,536	+46	+0.5
	+2,573	11,330	11,521	+191	+1.7
	-2,283	7,853	7,895	+42	+0.5
	+163	9,165	9,428	+263	+2.8
Steer D, 1908.....	-1,277	5,069	5,029	-40	-0.8
	-1,923	4,078	4,021	-57	-1.4
Steer E, 1908.....	+815	7,150	7,087	-63	-0.9
	-862	5,553	5,524	-29	-0.5
	-1,954	5,008	4,903	-105	-2.1
	+728	7,437	7,687	+250	+3.2
	-1,440	5,664	5,695	+31	+0.5
	-1,963	4,523	4,646	+123	+2.6
Steer C, 1908.....	-1,955	7,169	7,046	-123	-1.7
	-2,109	6,105	5,945	-160	-2.6
	-845	9,177	8,975	-202	-2.3
	-1,464	7,066	7,115	+49	+0.7
	-2,000	5,884	5,934	+50	+0.8
Steer F, 1909.....	+2,147	8,756	8,989	+233	+2.6
	-95	7,369	7,404	+35	+0.5
	-1,936	6,310	6,343	+33	+0.5
	+500	10,784	11,066	+282	+2.6
	-1,186	7,697	7,731	+34	+0.3
	-3,148	6,846	6,718	-128	-1.9
Totals and averages, 57 ex- periments.....	-45,904	488,102	490,117	+2,015	+0.4

As might be anticipated, in view of the numerous sources of error in experiments of this sort, the results of individual trials differ considerably, in some cases, from those required by the law of the conservation of energy, the extreme percentage differences being +7.6 and -5.1.

In the aggregate of a considerable number of experiments, however, these errors would tend to compensate each other, and, in fact, the total observed heat production for the 57 trials differs from that computed by only $+0.4\%$. This difference is of about the same order of magnitude as those observed by previous investigators, being slightly greater than Rubner's and slightly less than Laulanié's and Benedict's, although the range of error in the individual experiments is somewhat greater. Only the earlier averages of Atwater and Benedict show a materially closer agreement.

The conclusion seems warranted, therefore, that the same equivalencies between chemical energy, heat energy and mechanical energy obtain in the bodies of herbivorous animals as in those of carnivora or of man, and, as a rule, elsewhere in nature.

STATE COLLEGE, PA.

The Pennsylvania State College Agricultural Experiment Station

BULLETIN No. 126

FOOD AS BODY FUEL*

By HENRY PRENTISS ARMSBY

Director of the Institute of Animal Nutrition

In 1898 the United States Department of Agriculture proposed to The Pennsylvania Experiment Station that it undertake in co-operation with the Bureau of Animal Industry a series of investigations into the fundamental scientific principles of animal nutrition. The Department's proposition was accepted by the Trustees and after a study of the chief types of American and foreign apparatus, the construction of a respiration calorimeter modelled after the one devised by Atwater & Rosa at Middletown, Conn., for experiments upon man was begun. This apparatus was completed and the first series of experiments made in 1902, it being the first apparatus of the sort for experiments on domestic animals. When the agricultural work of the College was reorganized in 1907, this line of investigation had assumed so much importance that it was constituted a separate department, independent of the School of Agriculture and Experiment Station, although affiliated with it, under the name of the Institute of Animal Nutrition.

*Investigations under the Adams Act in cooperation with the Institute of Animal Nutrition and the Bureau of Animal Industry of the United States Department of Agriculture.

The investigations which the Institute of Animal Nutrition is conducting constitute a study of the fundamental principles of animal nutrition from that standpoint which regards the food of man or animals as the source of energy to the body.

The Animal a Prime Motor

The living animal constitutes what the engineer calls a *prime motor*, that is, it generates power for its own operation and is able to produce a surplus which may be used to do work of one sort or another. In particular there is a very close resemblance between the animal body and the various forms of internal combustion motors (oil, gas, gasoline, etc.,) which have become so familiar in recent years. Both are mechanisms designed to utilize the chemical energy stored up in fuel of one sort or another for the performance of work and the requirements of both are similar. To keep a device used for this purpose in running order repair material is necessary—steel, brass, etc., for the engine, proteins and mineral matters for the animal—but in both cases the chief demand is for fuel material.

Transformations of Energy

When fuel is burned in the cylinder of the engine the energy which it contains is transformed, part appearing as work but usually considerably more taking the form of heat, while if the engine is run without load, all the energy of the fuel used is changed into heat, in part directly in the cylinder and in part through the heating of the bearings by friction. Such an engine is spoken of as a transformer of energy because it changes one form of energy into another. The case of the animal body is precisely similar. The materials digested from its food are carried by the blood to the working tissues and there virtually burned. Part of their energy may be used to do visible external work, but even then much of it is converted into the form of heat, while in the animal in a state of so-called rest, the work done by the internal organs finally results in the generation of heat, somewhat as does the motion of the unloaded engine.

Food as Fuel

The food, then, may be regarded in the light of fuel for the bodily mechanism, and may be studied from this point of view.

With the aid of the elaborate apparatus, already mentioned, the Institute of Animal Nutrition is engaged in investigating the values of different feeding stuffs as sources of energy for the animal, seeking to determine the efficiency with which their energy can be used by different animals and under various external conditions. Similar investigations have been carried on elsewhere, notably by Kellner in Germany, and methods of comparing feeding stuffs and computing rations have been based upon the results.

Comparison with Engine

A fundamental question which at once arises, however, is whether we are really justified in comparing the burning of gasoline in an engine with the combustion of food materials in the body. In the one case the fuel is burned suddenly and almost or quite completely at a high temperature. In the body, the oxidations take place rather slowly, at a comparatively low temperature, and through many intermediate stages, and yield considerable amounts of incompletely burned products. Moreover, the animal machine is a *living* machine and we are not justified in assuming in advance of the evidence that energy is transformed in the living being in the same manner and according to the same laws as in lifeless matter.

The Conservation of Energy

In the case of the latter, it has been found in a great number of exact investigations that whenever one form of energy disappears an equivalent amount appears in some other form. Thus, if heat is produced by mechanical means, such as the fall of a body from a height, friction, or other means, the heat which appears is always exactly proportioned to the mechanical energy used up in producing it. If the stored up energy of gasoline is used to run an engine, the work done plus the heat produced always bears the same relation to the energy contained in the gasoline burned. This universal experience is expressed in the *law of the conservation of energy*, which asserts in substance that energy is indestructible. It may change its form, but its total amount is neither increased nor diminished. Is this law true of the animal motor? Does the combustion of its feed set free the same amount of energy in the body as if it were burned as fuel to operate an engine? If it does, then, if we were to measure on the one hand the work plus the heat

produced by an animal, or more simply still if we were to experiment on an animal doing no work and measure its heat production, the latter should be equal to the heat which would be produced by burning the same materials outside the body. In other words, the question just raised may be substantially answered by experiments upon the origin of animal heat.

Origin of Animal Heat

Every one knows that animals produce heat, but only in comparatively recent years has the origin of that heat been fully demonstrated. To the ancients it was entirely a mystery. They located it in the heart and their attempted explanations of its source were simply verbal. Galen, for example, speaks of it as "That heat which is innate in the heart, which was placed there as the source of the heat of the body by God in the beginning of life and which remains there until death."

Not until oxygen was discovered almost simultaneously in 1774 by Priestly in this country and by Scheele in Sweden, and until the investigations of Lavoisier had demonstrated its relations to combustion, was a rational understanding of the origin of animal heat possible. In 1777 Lavoisier showed that the oxygen of the air taken into the lungs in respiration serves to maintain a process of slow combustion in the body. This he regarded as the source of the animal heat and a little later he succeeded in measuring the heat produced by a guinea pig and found its amount to correspond approximately to that to be expected from the amount of material burned in the body.

This view of the matter, however, was far from being accepted by Lavoisier's contemporaries and even yet there is often a feeling that "animal heat" is somehow different from other heat—that for example the removal of the animal heat from milk is something different from simple cooling—but still it has come to be generally recognized that the heat which every living animal produces has its origin in the burning within the body of the materials supplied by the food. The temperature of a tight stable is kept above that of the outer air by the combustion in the bodies of the animals of the nutrients digested from the hay and grain which they consume. In the further development of this idea, feeding stuffs have now come to be regarded largely in the light of fuel for

the animal machine, supplying energy for its motions and, more or less incidentally, heat to keep it warm while any surplus food is stored up in the form of fat as a reserve of fuel material against future needs.

Computed and Observed Heat Production

As just stated, Lavoisier believed that he had shown that the combustions in the body accounted for the heat produced. This novel view led to a number of experiments by subsequent investigators who failed to obtain as good an agreement as did Lavoisier. We now know of numerous sources of error in these experiments as well as in Lavoisier's, however, so that they are of little value as evidence. Only within the last twenty years has the development of scientific methods rendered possible really accurate investigations of this question. Within that time several investigators have taken it up by substantially the method just outlined, *i. e.*, they have compared the heat actually produced by an animal with that which would be produced by the burning of the same materials outside the body.

Experiments on Dogs

The first investigation of this sort was made by Rubner in Germany in 1894 on two dogs. In the aggregate of experiments covering 45 days, the actual heat production as determined by Rubner's form of animal calorimeter agreed closely with the amount computed from the body oxidations, as the following comparison shows. The small difference of one-third of one per cent. is quite within the limits of unavoidable error in such experiments.

Computed heat production.....	17406.0	Cals.*
Observed heat production.....	17349.7	"

Difference -56.3 " = -0.32%

About four years later Laulanié in France reported similar comparisons on several different species, by what appear to have been somewhat less rigorous methods, which likewise showed a close agreement, the observed differing from the computed heat production in the aggregate of all the experiments reported in full by -0.31%.

*A calorie (abbreviation, Cal.) is the amount of heat required to raise the temperature of one kilogram of water 1°C, or that of one pound of water about 4°F. For all the purpose of this bulletin, however, it is sufficient to regard it as the unit used in measuring heat, just as a yard is a unit of length.

Experiments on Men

The most extensive investigations of this sort are those made in this country by Atwater, Benedict and their associates upon men. In a number of these experiments the subject did considerable mechanical work which was converted into heat inside the apparatus. In 30 experiments reported up to the year 1902 and covering 93 days, the total observed and computed heat production and the percentage difference were:

Computed heat production.....	249063	Cals.
Observed heat production.....	248930	"
Difference	-133	" = -0.05%

Benedict & Milner in 11 later experiments, aggregating 24 days, with an improved form of apparatus, obtained the following results:

Computed heat production.....	95075	Cals.
Observed heat production.....	95689	"
Difference	+614	" = +0.65%

Still later Benedict reported 18 experiments upon men, covering in all 53 days, which gave the following results:

Computed heat production.....	102078	Cals.
Observed heat production.....	101336	"
Difference	-742	" = -0.73%

Few Results on Herbivora

These results show beyond reasonable doubt that the animal heat produced in dogs and in man is exactly accounted for by the amounts of food and body material burned during the same time. The experiments, however, with the exception of a few of Laulanié's, did not include herbivorous animals, the class to which the more important farm animals belong. For various reasons, therefore, direct investigations upon these animals, and in particular upon ruminants, appear desirable. Not only do these animals differ as regards their digestive and other processes from carnivorous animals and from man, but in particular the newer method of comparing the nutritive values of feeding stuffs for farm animals which has been introduced by Kellner—his "starch values" which

are really energy values—practically assumes that energy is utilized in the animal body in accordance with the same general laws as elsewhere.

Experiments on Cattle

The investigations begun here in 1902 afford data upon this point. The experiments have been upon mature or nearly mature cattle. In each of them the quantities and kinds of material burned in the body were ascertained by comparing the amounts of the different chemical elements contained in the feed with those found in the excreta, including especially the gases given off by the animal, which were determined by means of the respiration calorimeter. This same apparatus permits the exact determination at the same time of the amount of heat produced by the animal, which can then be compared with that computed from the materials oxidized. The results of 57 such experiments of 2 days each on 7 different animals, including all which had been completed and computed up to the close of the year 1909, are given in the table appended to this bulletin. A reference to that table shows that while the results of individual trials differ more or less, sometimes the computed heat production and sometimes the observed being slightly the greater, the differences are in both directions and in the aggregate a very close agreement is found, the total figures being:

Computed heat production.....	976204	Cals.
Observed heat production.....	980234	"
Difference	+4030	" = +0.41%

If the unsatisfactory results of the year 1905 be omitted, the discrepancy is reduced to -0.07%.

These results may be taken as demonstrating that the conversion of the energy of the feeding stuffs of our farm animals into heat and work is governed by the same general laws which apply to other classes of animals and to the transformations of energy in lifeless matter. The results, therefore, fully justify basing comparisons of the values of feeds upon their content of energy in forms available to the animal organism.

Summary of all Experiments

Finally, it is of interest to sum up the results, of all the reported experiments upon this subject, as has been done in the following table which shows the total computed and observed heat produc-

tion of all these experiments taken together. The difference between the two is one-quarter of one per cent, or quite within the limits of accuracy of experimental methods of this sort.

Experimenter.	Total number of days	Total computed heat production Cals.	Total observed heat production Cals.	Percentage difference
Rubner	45	17406	17350	- 0.32
Laulanié	7	1865	1859	- 0.31
Atwater & Benedict...	93	249063	248930	- 0.05
Benedict & Milner....	24	95075	95689	+ 0.65
Benedict	53	102078	101336	- 0.73
Armsby & Fries.....	114	976204	980234	+ 0.41
	336	1441691	1445398	+ 0.26

Conclusions

These results may be taken as demonstrating that the animal heat arises exclusively from the combustions in the body, but they have a much broader significance. They show that the transformations of chemical energy into heat and work in the animal body take place according to the same general laws and with the same equivalencies as in our artificial motors and in lifeless matter generally. The great law of the conservation of energy rules in the animal mechanism, whether in man, carnivora or herbivora, just as in the engine. The body neither manufactures nor destroys energy. All that it gives out it gets from its food and all that is supplied in its food is sooner or later recovered in some form. We are fully justified, therefore, in speaking of the food as body fuel, and in our studies of its utilization we may be confident that any food energy which does not reappear in the form of heat or work has not been lost but has been stored up in the body as the chemical energy of meat, fat, etc., which may later serve to supply food energy to the human body when consumed as food by man.

Observed and Computed Heat Production of Cattle. 48-hour Experiments.

	Gain by animal Cals.	Heat Production		Difference	
		Computed Cals.	Observed Cals.	Cals.	Per cent.
Steer I 1902	- 5482 - 1614 - 18 + 1048	18486 20402 22232 23154	18430 20592 21498 22986	- 56 + 190 - 734 - 168	-0.3 +0.9 -3.4 -0.7
Steer I 1903	- 6818 - 8358 - 5036 + 7582	23270 20246 21310 28362	23058 20246 21080 29304	- 212 0 - 230 + 942	-0.9 0 -1.1 +3.2
Steer I 1904	-10486 -10748 - 2678 - 2172 - 5430 - 5540	22028 22370 23960 23454 22548 22132	21822 23472 22870 22636 21448 21750	- 206 +1102 -1090 - 818 -1100 - 382	-0.9 +4.7 -4.8 -3.6 -5.1 -1.8
Steer A 1905	- 2520 + 2234 - 4878 - 2542	16094 17652 11958 14570	17212 18298 12392 14712	+1118 + 646 + 434 + 142	+6.5 +3.5 +3.5 +1.0
Steer B 1905	- 1636 + 1658 - 3738 - 1070	12758 13802 9650 10692	13242 14654 10442 10868	+ 484 + 852 + 792 + 176	+3.6 +5.8 +7.6 +1.6
Steer A 1906	+ 2736 + 8610 - 5020 - 574	18498 25764 14690 16330	18678 25744 14904 16418	+ 180 - 20 + 214 + 88	+1.0 -0.1 +1.4 +0.5
Steer B 1906	- 1280 + 2266 - 4094 - 876	18106 19400 13418 14896	17874 19472 13856 14760	- 232 + 72 + 438 - 136	-1.3 +0.4 +3.2 -0.9
Steer A 1907	+ 3398 +12682 - 3310 + 1256	20480 28180 15532 18814	20348 28280 15546 18986	- 132 + 100 + 14 + 172	-0.6 +0.4 +0.1 +0.9
Steer B 1907	- 332 + 5146 - 4566 + 326	18980 22660 15706 18330	19072 23042 15790 18856	+ 92 + 382 + 84 + 526	+0.5 +1.7 +0.5 +2.8
Steer D 1908	- 2554 - 3846	10138 8156	10058 8042	- 80 - 114	-0.8 -1.4

Observed and Computed Heat Production of Cattle—Cont.
48-hour Experiments.

	Gain by animal Cals.	Heat Production		Difference	
		Computed Cals.	Observed Cals.	Cals.	Per cent.
Steer E 1908	+ 1630	14300	14174	— 126	—0.9
	— 1724	11106	11048	— 58	—0.5
	— 3908	10016	9806	— 210	—2.1
	+ 1456	14874	15374	+ 500	+3.2
	— 2880	11328	11390	+ 62	+0.5
Steer C 1908	— 3926	9046	9292	+ 246	+2.6
	— 3910	14338	14092	— 246	—1.7
	— 4218	12210	11890	— 320	—2.6
	— 1690	18354	17950	— 404	—2.3
	— 2928	14132	14230	+ 98	+0.7
Steer F 1909	— 4000	11768	11868	+ 100	+0.8
	+ 4294	17512	17978	+ 466	+2.6
	— 190	14738	14808	+ 70	+0.5
	— 3872	12620	12686	+ 66	+0.5
	+ 1000	21568	22012	+ 444	+2.0
Totals and averages 57 experiments...	— 2372	15394	15462	+ 68	+0.3
	— 6296	13692	13436	— 256	—1.9
49 experiments omitting those of 1905...	—91808	976204	980234	+4030	+0.4
	—79316	869028	868414	— 614	—0.07

Reprinted from THE JOURNAL OF BIOLOGICAL CHEMISTRY, Vol. XIX, No. 1, 1914

A STUDY IN DRYING URINE FOR CHEMICAL ANALYSIS.

By WINFRED W. BRAMAN.

(From the Institute of Animal Nutrition of the Pennsylvania State College, State College, Pa., in coöperation with the Bureau of Animal Industry of the United States Department of Agriculture.)

(Received for publication, July 27, 1914.)

In the determination of the heat of combustion of urine it is necessary first to get rid of the large amount of water present. During the drying to remove this water, decomposition takes place giving rise to a loss of substance and therefore to a loss of energy.

Many suggestions¹ have been made as to the method of drying. Farkas and Korbuly² made an extensive study of the calorimetry of urine. They reviewed the work done by Rubner, Kellner and others and concluded that the smallest loss of energy occurred when drying the urine in vacuum at room temperature, without any addition whatever. They further concluded that it mattered very little in practical calorimetry whether Rubner's correction of 5.45 calories, or Krummacher's correction of 6.518 calories per gram of nitrogen lost, was used. Most of this work was done with the urine of omnivora and carnivora and but little with that of herbivora. In every case particular attention has been paid to the loss of nitrogen with almost no attention to the loss of carbon.

The plan of this experiment was to dry steer's urine in such a manner that the loss of carbon as well as the loss of nitrogen could be determined and therefore possibly some relationship established between the two. Further, urines were to be dried by different methods as regards temperature, etc., and energy determinations made on the residues so as to see if a change in the loss of carbon and nitrogen made a definite change in the energy value.

¹ Glikin: *Kalorimetriscbe Methodik*, p. 67; Neuberg: *Der Harn*, ii, p. 1323.

² Farkas and Korbuly: *Arch. f. d. ges. Physiol.*, civ, p. 564.

In the metabolism experiments it was impracticable to make analyses daily. Each urine used for analysis was a composite sample covering the urine of ten successive days, the animal being fed a definite ration. These samples were preserved in rubber-stoppered bottles, with the addition of a few cubic centimeters of chloroform. The bottles were kept in a refrigerator. Always to make sure that the compositing was accurate, total nitrogen determinations were made upon the daily urines on the days of compositing. The true average per cent of total nitrogen for the ten days always agreed very closely with the per cent of total nitrogen determined upon the composite.

Two methods of drying were used. The one was to dry 10 gram charges, in platinum capsules in Hempel desiccators at about 5 mm. vacuum, using concentrated sulphuric acid as the drying agent. Samples could thus be dried at any desired room temperature.

The second method was to dry charges of 5–10 grams of urine in platinum boats or capsules in a current of dry NH_3 - and CO_2 -free air. This current after passing over the urine bubbled through a known amount of $\frac{5\text{N}}{14} \text{H}_2\text{SO}_4$. Then it was dried by concentrated H_2SO_4 , and drawn through a train of absorption tubes to remove CO_2 . The NH_3 was determined in the standard acid and the CO_2 by absorption with soda lime.

The glass tubes carrying the platinum dishes with charges were in a special form of water oven, the ends of the glass tubes projecting to either side of the oven, the temperature of which was electrically regulated. Also the oven could be turned over and the chamber about the glass tubes packed with ice so as to produce low temperatures.

This method of drying allowed the determination of the total loss of NH_3 and of CO_2 on drying. It gave no information as to whether the NH_3 and CO_2 were present as such in the urine or were derived from some decomposition during drying. To test this in the fresh urine, NH_3 was determined by Steele's modification of Folin's method and the free NH_3 by Folin's method modified by the addition of some NaCl . In connection with the determination of free NH_3 , an effort was made to determine the free CO_2 , by conducting the air current, dry and NH_3 -free,

through an absorption train, thus absorbing the CO_2 in the soda lime.

In the routine analytical work connected with the experiments with the respiration calorimeter, the total carbon and organic hydrogen were determined. This was done by burning in a quartz combustion tube, with copper oxide, the residues dried in an air current at $55^\circ\text{--}60^\circ\text{C}$. The carbon thus obtained was corrected by adding the carbon of the CO_2 lost on drying and the hydrogen was corrected by adding the hydrogen of the NH_3 lost on drying. This method did not tell whether or not all of the carbon lost on drying consisted of CO_2 .

It was decided to try burning fresh urine in the usual combustion furnace tube and thus get the total carbon and total hydrogen, including that of the water, at once. These combustions were made in a quartz tube containing a 50 cm. layer of copper oxide and beyond at the exit end a 20 cm. layer of reduced copper in spiral or wire-gauze form. The charge of 4–5 grams fresh urine was weighed by difference into a porcelain boat 12 cm. long containing, at first some ignited asbestos, but later a strip of reduced copper gauze. The charge was put into the boat as it lay in the combustion tube, projecting a little for the time being. All charges of urine were weighed by difference from a small 30–40 cc. flask, rubber stoppered, the stopper carrying a medicine-dropper pipette.

The absorption train at the exit end of the combustion tube consisted for the water, of a Peligot tube containing concentrated H_2SO_4 followed by an acid pumice U-tube. Later a Winkler-Kyll absorption bulb was used. Some such form of apparatus was necessary to avoid sucking back of acid into the combustion tube when any considerable amount of water was absorbed. For the absorption of CO_2 , one or two soda lime U-tubes with two acid U-tubes were used.

After putting in the charge and a copper spiral after it, the quartz tube was heated for two-thirds of its length, beginning at the exit end, until red hot. Then a current of dry CO_2 -free air was forced over the urine through the heated tube into the absorption train. The tube immediately about the charge had to be kept cool to the finger tips. In about one and one-half hours the urine charge was nearly dry and most of the water had gone over into the acid absorption bulb, or had condensed about the

exit end of the combustion tube. At this time the remaining third of the combustion tube was heated gradually to redness. After about all of the condensed water had left the exit end of the tube, the heat under the reduced copper spiral was turned off and the stream of air was changed to a stream of oxygen. This

TABLE I.

Total carbon and total hydrogen in steer's urine. Percentage computed on fresh substance.

SAMPLE NO.	TOTAL CARBON, CARBON IN RESIDUE + CARBON LOST ON DRYING	TOTAL CARBON BY BURNING FRESH URINE	TOTAL HYDROGEN BY BURNING FRESH URINE
	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>
1162	1.953	1.961	10.548
	1.989	1.904	10.525
		2.099	
		2.066	
1189	1.278	1.338	10.859
	1.278	1.292	10.866
		1.336	10.712
1215		1.406	10.772
		1.379	10.775
		1.434	10.793
1239		1.505	10.761
		1.530	10.869
		1.484	10.762
1274	2.020	2.080	10.572
	2.060	2.047	10.527
1300		1.668	10.694
		1.653	10.571
		1.619	10.642
			10.630
1325			10.663
		1.555	10.701
		1.662	10.708
		1.698	10.684
1369		1.609	10.684
		1.784	10.671
		1.773	10.640

was continued for some time after the exit end of the tube was dry and until oxygen was detected at the end tube of the absorption train. The reduced copper successfully decomposed the oxides of nitrogen and held the chlorine of the volatile salts. The method gave accordant results as shown in table I.

The percentage of total carbon by the new method compared with the total carbon computed from the loss as CO₂ and the carbon in the residue shows that the total loss of carbon on drying was from CO₂.

TABLE 2.

Analyses of steer's urine. Percentage computed on fresh substance.

SAMPLE NUMBER	1162	1189	1215	1239	1274
	3 kg. starch 7.5 kg. al- falfa hay	1.2 kg. starch 3 kg. alfalfa hay	1.7 kg. starch 4.25 kg. al- falfa hay	0.8 kg. starch 2 kg. alfalfa hay	9 kg. alfalfa hay
Daily feed.....					

By direct determination.

	N	C	N	C	N	C	N	C	N	C
	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>
Total.....	0.934	1.995	0.711	1.304	0.691	1.406	0.899	1.506	1.322	2.052
Loss as NH ₃ compds. including NH ₃	0.415		0.401		0.334		0.146		0.074	
Loss as free NH ₃	0.138		0.156		0.125		0.073		0.034	
Loss on drying in air current at 55°-60°C.....	0.441	0.524	0.432	0.333					0.097	0.270
Loss on drying in air current at 10°-20°C.....			0.427	0.363	0.343	0.254				
Loss on drying in air current below 10°C.....			0.424	0.412						

Indirectly by computation from determinations on residues.

Loss on drying in vacuum at 20°C.....	0.412	0.474	0.427	0.312	0.371	0.362	0.150	0.204	0.058	0.179
Loss on drying in vacuum, while frozen.....					0.326	0.302			0.061	0.184

Briefly the determinations made were the following: in fresh urine, total nitrogen, total carbon, total hydrogen, nitrogen as NH₃ and NH₄ together, and nitrogen as NH₃; (CO₂ as such was tried but not successfully); in the residues dried in vacuum in Hempel desiccators, carbon, nitrogen and energy; in the drying in air current, the loss of carbon as CO₂ and the loss of nitrogen as

NH₃; in the residues dried in air current, carbon, nitrogen and energy.

The nitrogen was determined always by the Kjeldahl method. The energy was determined in an Atwater-Hempel bomb, using the Fries adiabatic³ device.

The drying in Hempel desiccators was tried at room temperature of about 20°C., and also at a little above 0° after having first frozen the urine charges. The drying in air current was tried at 55°-60°C, at 10°-20°C. and also at below 10°.

The summarized results are shown in Table 2.

The losses on the samples dried in Hempel desiccators are computed by difference. The percentages are the averages of from two to six determinations.

The table shows that in the case of the nitrogen the losses by the different methods differed only slightly. Further the determinations of the nitrogen of free NH₃ and of NH₄ compounds by Steele's modification of Folin's method gave in every case an amount of nitrogen only slightly less than the greatest loss on drying, even at 55°-60°. Thus we have,

URINE NO.	GREATEST LOSS ON DRYING, PER CENT N	FREE NH ₃ AND NH ₄ COMPOUNDS PER CENT N
1162	0.441	0.415
1189	0.432	0.401
1215	0.371	0.334
1239	0.150	0.146
1274	0.097	0.074

Since this method liberates no NH₃ from urea, uric acid or hippuric acid, it is fair to conclude that the greater part of the nitrogen lost came from free NH₃ and NH₄ compounds. In every case some free NH₃ was found.

With the Folin method for free NH₃ some difficulty was found in that not only free NH₃ but also NH₃ from NH₄ compounds was taken out of the urines during the determinations. It was found that the addition of 10 grams of sodium chloride to a charge of 5 grams of urine prevented some ammonium salts from breaking up.⁴

³ Fries: *Journ. Amer. Chem. Soc.*, xxxiv, p. 643.

⁴ From unpublished results by D. C. Cochrane of this Institute.

This subject is now being taken up in this laboratory.

In respect to the carbon, the losses on drying were somewhat greater for the higher temperatures. The variation was greater than with the loss of nitrogen. With each urine the determination of free CO₂ was tried. Always some CO₂ was found but no results were obtained which checked.

The fact that all of the carbon that was lost was CO₂ and that nearly all of the nitrogen lost was from NH₄ compounds and free NH₃, points decidedly to the presence of ammonium carbonates. Also, from the fact that always more carbon was lost than would be required to combine with the nitrogen lost for the formation of normal carbonate, it seems reasonable to suppose some bicarbonate was present in the urine.

At the time it was found impossible to dry enough samples so that sufficient energy determinations could be made to attempt any definite conclusions regarding the relation of differences in losses to differences in energy. Energy determinations were made upon some of the dried residues. Energy values of residues obtained by drying under differing conditions were determined only on urine 1274, the sample showing the smallest loss of nitrogen and carbon on drying.

Sample No. 1274	Calories per gram fresh substance
In residues obtained by	
drying in air current 55°-60°.....	186.89
drying in vacuum at 20°.....	194.72
drying in vacuum after freezing.....	193.49

The above figure 186.89 is the mean of the two results differing by six calories which is not a good agreement. The values for the residues dried at 20° and while frozen are the averages of three and two determinations respectively, differing by less than one calorie.

Determinations for urea and hippuric acid were not made, owing to lack of time and equipment. Undoubtedly these would have helped in determining any relation between carbon and nitrogen, knowing the free CO₂ and NH₃.

According to J. Tereg,⁵ the nitrogen content of cattle urine is principally in urea and hippuric acid, in all cases the urea being

⁵ Tereg: *Ellenberger's Physiologie der Haussäugethiere*, i, p. 390.

the main carrier of nitrogen. Even with urines rich in hippuric acid fully two-thirds of the total nitrogen belongs with the urea. There seemed to be no relation between the urea content and the hippuric acid content.

Quite different from the above are the results found with urines 1162, 1189 and 1215. In these urines only 55.5, 43.6 and 51.6 per cent respectively, of the total nitrogen was present in some form other than NH_4 compounds and free NH_3 . In urines 1239 and 1274, 83.7 and 94.4 per cent respectively, of the total nitrogen was present in some form other than NH_4 compounds and free NH_3 . These results show plainly that in some urines one-half of the total nitrogen can be in the form of NH_4 compounds and free NH_3 .

As regard the relation of the different feeds to the quantities of carbon and nitrogen obtained, not much can be stated. The small loss of nitrogen in urines 1239 and 1274, a very light ration of starch and hay and a heavy ration of hay alone, respectively, indicates the presence in the urine of organic compounds not so readily broken up by a temperature as high as 60°C . or by bacterial or enzyme action. It is to be noted that the total nitrogen in urine 1274 is much higher than of any of the other urines.

The method of making up the samples and the time of making determinations should be considered. The first aliquot of each composite sample was ten days old, the second, nine days old and so on, before any determinations on the composite sample could be started. The true average per cent of daily nitrogen showed there was no loss of nitrogen from the composite but did not detect any rearrangement of nitrogen compounds within the urine during the compositing. Very recently Dehn and Hartman⁶ have studied preservatives for urine and show how difficult it is to preserve urine for chemical analysis. In regard to the urines used here, it is a question as to what would have been the result had the fresh daily urines been used for analysis instead of the composite samples. Such an undertaking would be impossible without a special force and equipment.

⁶ Dehn and Hartman, *Journ. Amer. Chem. Soc.*, xxxvi, p. 409.

SUMMARY OF CONCLUSIONS.

The data presented below show

1. That in some urines from herbivora, on drying, the loss of nitrogen from NH_4 compounds and free NH_3 may be as high as 50 per cent of the total nitrogen of the urine.
2. That the carbon lost consists of CO_2 and is more than enough in quantity to combine with the NH_3 lost to form normal carbonates.
3. That the loss of nitrogen comes mainly from the decomposition of ammonium carbonate and not from the decomposition of urea or hippuric acid.
4. That the loss of carbon comes partly from the normal carbonate and partly from the bicarbonate.
5. That the total carbon and total hydrogen, including that of water, can be determined directly by combustion in a quartz combustion tube, using the ordinary combustion furnace.

NET ENERGY VALUES OF FEEDING STUFFS FOR CATTLE

By HENRY PRENTISS ARMSBY, *Director*, and J. AUGUST FRIES, *Assistant Director*,
Institute of Animal Nutrition of The Pennsylvania State College

COOPERATIVE INVESTIGATIONS BETWEEN THE BUREAU OF ANIMAL INDUSTRY
OF THE UNITED STATES DEPARTMENT OF AGRICULTURE AND THE INSTITUTE
OF ANIMAL NUTRITION OF THE PENNSYLVANIA STATE COLLEGE

INTRODUCTION

Besides supplying certain specific forms of matter (ash ingredients, proteins, lipoids, carbohydrates, vitamins, etc.) essential to the normal course of metabolism, the feed of an animal is, so far as we know, the sole source of the energy whose transformations constitute the essential phenomena of physical life. This energy is contained in the feed as chemical energy, and the maximum quantity which any substance can furnish for the vital activities by its oxidation in the body is measured by its heat of combustion. It rarely, if ever, happens, however, that this maximum effect is realized. In practically every case a larger or smaller proportion of the chemical energy of the feed escapes unutilized. These losses of energy are of two general classes.

First, a portion of the chemical energy of the feed fails to be transformed at all, leaving the body as chemical energy in the visible excreta and in the combustible gases arising from gastric and intestinal fermentations.

Second, another portion of the chemical energy of the feed is indeed transformed, but at ordinary temperatures virtually results merely in a superfluous heat production. It is true that the metabolism consequent upon feed consumption is not only unavoidable but may be regarded as a necessary expenditure of energy for the support of the activities connected with digestion and assimilation. Nevertheless, from the standpoint of the net gain or loss by the organism this portion of the feed energy, which ultimately takes the form of heat and escapes from the body, must be regarded as a loss.

The remainder of the chemical energy in the feed, after deducting these two classes of losses, has been designated as its net energy value and

expresses the net effect of the feed either in causing a storage of chemical energy in the form of fat, protein, etc., in the body, or, in the case of a submaintenance ration, in diminishing the amount of energy which must be supplied by the katabolism of body tissue.

The investigations of the last 30 years have shown that both the general problems of nutrition and the economic questions relating to the feeding of domestic animals may be advantageously studied from the standpoint of energetics. From this standpoint, it is of importance to determine as accurately as may be the losses of energy which feed substances undergo in the two ways just mentioned and the resulting net energy values. In the following pages are reported the results of a considerable number of experiments on cattle carried out at this Institute during the years 1902 to 1912, inclusive, in which these losses have been determined for certain feeding stuffs.¹ These experiments up to the end of 1907 have been already reported in full (7, 8, 9, 10)² and it is hoped to discuss the details of the later ones in subsequent papers. Here it will be convenient, following a general description of the experiments, to consider:

- I. The losses of chemical energy.
- II. The expenditure of energy consequent upon feed consumption and its factors.
- III. Net energy values and their computation.

GENERAL DESCRIPTION OF THE EXPERIMENTS

The experiments were made with the aid of a respiration calorimeter of the Atwater-Rosa type, the essential features of which have already been described (3, 4, 7). The apparatus permits a determination of the water vapor and carbon dioxide excreted, of the carbon and hydrogen in the combustible gases produced, and of the heat given off, but not of the oxygen consumed. In addition to the ordinary feeding stuffs analyses of feed and excreta, the quantitative collection of the feces and urine and the determination of the amounts of carbon, hydrogen, and energy contained in them were also necessarily involved. The experiments comprised, in all, 76 single feeding periods. Each period covered at least 3 weeks, of which 11 days or more constituted a preliminary period, while the visible excreta were collected for the last 10 days, during which, on the seventh and eighth days, the complete balance of matter and energy was determined for 48 consecutive hours in the respiration calorimeter.³ The accuracy of this instrument was tested by means of numerous alcohol checks. The results of 18 such checks (10, p. 217-222) showed that the

¹ In all, over 30 persons have taken a more or less direct part in the respiration trials and in the large amount of analytical, clerical, and miscellaneous work involved in the experiments. For obvious reasons, it is impossible even to attempt any statement of the exact part taken by individuals or to make acknowledgments for the specific work done by each person. This is all the more true because the most important factor in whatever success the investigation has attained, and one which by its nature is incapable of such partition, is the loyalty and zeal which all concerned have shown in the execution of the plan of the investigation and in securing the greatest attainable accuracy of details.

² Reference is made by number to "Literature cited," p. 489-491.

³ For details regarding the methods employed compare the bulletins of the Bureau of Animal Industry already cited (7, 8, 9, 10), especially Bulletin 128 (10), p. 200-216, as well as the detailed descriptions of the single experiments contained in that bulletin.

values obtained in a single experiment may be regarded as accurate to within the following percentages of the amounts determined: Carbon dioxide, 0.5; water, 6.0; heat, 1.0.

A further test of the accuracy of the work is found in a comparison of the observed heat production with that computed in the ordinary way from the balance of carbon and nitrogen. Comparisons of this sort for 57 feeding periods up to the end of 1909 (5, 6) showed an average difference of 0.4 per cent. The results of the later comparisons reduce this difference to 0.3 per cent, or, if the unsatisfactory results of the year 1905 be omitted, to 0.04 per cent. The total amounts of heat involved are as follows:

		76 periods.	68 periods.
Computed heat production	Calories..	1,338,887	1,231,711
Observed heat production	do....	1,343,071	1,231,251
Difference	do....	4,184	460
Percentage difference		0.31	0.04

While the basis for the computation of the heat production is not altogether satisfactory, especially in the absence of determinations of the gain or loss of glycogen by the animal, nevertheless the general agreement is such as apparently to preclude the existence of gross errors.

FEEDING STUFFS

The dry matter of the several feeding stuffs used had the following average composition, as shown in each case by concordant analyses of two or more separate samples taken at the beginning of each experiment (Table I). The more important determinations were also repeated upon samples taken when the feed was weighed out for each period, and these period results form the basis of the computations on subsequent pages.

TABLE I.—Composition of the dry matter of the feeding stuffs

Feeding stuff and experiment No.	Ash.	Protein.	Non-protein.	Crude fiber.	Nitrogen-free extract.	Ether extract.	Heat of combustion per kilogram.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Calories.
Timothy hay:							
174.....	4.64	5.11	0.24	38.92	49.01	2.08	4,554
190.....	4.87	5.08	.39	38.15	49.51	2.01	4,431
200.....	5.86	6.72	.83	33.02	51.01	2.56	4,516
207.....	5.01	6.90	.24	31.15	54.55	2.15	4,505
Red clover hay:							
179.....	6.40	12.90	1.61	31.61	44.81	2.67	4,457
186.....	6.57	11.18	.89	28.78	49.65	2.93	4,492
Mixed hay:							
211.....	7.01	9.62	1.29	33.78	46.00	2.30	4,396
Alfalfa hay:							
208.....	9.40	11.86	2.52	31.96	42.75	1.51	4,403
209.....	10.76	12.09	1.67	31.70	41.86	1.92	4,330
212.....	9.06	12.39	2.86	30.10	43.63	1.96	4,368
Alfalfa meal:							
212.....	9.24	11.75	2.87	31.12	43.17	1.85	4,374
Maize stover:							
210, total.....	6.14	4.09	.86	36.15	51.46	1.30	4,337
210, portion eaten	6.67	4.46	.98	35.23	51.25	1.41	4,332

TABLE I.—Composition of the dry matter of the feeding stuffs—Continued

Feeding stuff and experiment No.	Ash.	Protein.	Non-protein.	Crude fiber.	Nitrogen-free extract.	Ether extract.	Heat of combustion per kilogram.
Maize meal:	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Calories.</i>
179.....	1.37	9.94	.48	2.60	81.38	4.23	4,431
211.....	1.62	9.29	.24	3.16	80.64	5.05	4,517
Wheat bran:							
190.....	7.52	14.50	.49	11.49	61.88	4.12	4,532
Grain mixture No. 1: ^a							
200.....	4.10	16.97	3.43	6.09	62.89	6.52	4,690
207.....	4.14	17.95	2.22	6.16	64.38	5.15	4,670
Grain mixture No. 2: ^b							
208.....	2.78	12.07	.78	5.63	73.65	5.09	4,604
209.....	2.54	13.21	.54	5.81	72.77	5.13	4,617
Hominy chop:							
211.....	2.75	9.33	1.29	5.13	72.65	8.85	4,709

^a Wheat bran, 14.28 per cent; maize meal, 42.86 per cent; old process linseed meal, 42.86 per cent.
^b Maize meal, 60 per cent; crushed oats, 30 per cent; old process linseed meal, 10 per cent.

ANIMALS

Nine different steers have been used, varying in age from 11 months to approximately 60 months at the beginning of the several experiments.¹ They were either full bloods or high grades of recognized beef breeds, with one exception, steer B, which was distinctly of the dairy type and of mixed breeding (scrub), Jersey blood apparently predominating. All were docile animals and were thoroughly accustomed to the necessary handling, to wearing the apparatus for the collection of excreta, and to their surroundings in the digestion stall and the calorimeter. Further particulars concerning them are contained in Table II.

TABLE II.—Description of the animals used in the experiments

Animal No.	Breed of animal.	Nos. of experiments in which used.	Age at beginning of each experiment.	Average live weight in each experiment.
			<i>Months.</i>	<i>Kilograms.</i>
I.....	Grade Shorthorn.....	174	36	408
		179	48	528
		186	60	572
A.....	Aberdeen Angus.....	190	11	274
		200	23	408
		207	35	510
B.....	Scrub.....	190	13	195
		200	25	303
C.....	Grade Hereford.....	207	37	380
		208	9	275
D.....	do.....	208	9	167
		210	21	331
E.....	do.....	211	33	449
F.....	do.....	208	9	208
G.....	Full-blood Hereford..	209	21	300
H.....	Full-blood Shorthorn..	211	28	379
		212	20	345

¹ The word "experiment" is here used to designate the work of an entire season, including several feeding periods.

I. LOSSES OF CHEMICAL ENERGY—METABOLIZABLE ENERGY

The losses of chemical energy occur substantially in the feces and urine and in the combustible gases.

The energy content of the dried feces and urine is readily determined. In investigations at this Institute, Braman (16) has shown that the loss of energy in the drying of urine may be estimated with a good degree of accuracy, the error being insignificant in comparison with the total energy of the feed. The possible loss of energy in the drying of the feces has not yet been investigated directly, although Fingerling, Köhler, and Reinhardt (18) have observed a loss of carbon, the amount of which they do not state.

The energy content of the combustible gases is not susceptible of direct determination, but must be estimated from their chemical composition. The combustible gases which have been actually identified as excreted by cattle are methane and hydrogen. All investigations are in accord in showing that the former is the chief product of the normal fermentations occurring in the digestive tract, but results differ regarding the extent to which hydrogen is formed. In our experiments the gases were analyzed by passing them over platinized kaolin at a red heat. By this method in almost every instance a ratio of C to H slightly greater than that in CH₄ (2.976 to 1) has been found, the average of 57 experiments reported by the junior author elsewhere (19) being 3.167 to 1, with considerable variations in individual cases. We are inclined to think that this high figure is due to failure to oxidize the last traces of hydrogen in the combustion tube. On the other hand, Markoff (37, 38), in his extensive investigations of paunch fermentation in cattle, found in nearly every instance a small amount of hydrogen, and Von der Heide, Klein, and Zuntz (20), in respiration experiments upon an ox, observed a small excretion of hydrogen in two cases out of four. In computing the energy losses in the following experiments it has been assumed that the combustible gases consisted of CH₄ (methane), and the computations have been based upon the observed quantity of carbon.

The difference between the chemical energy of the feed and that lost in the excreta shows how much of the former is capable of being converted into other forms in the body, either during the changes which the feed undergoes in the digestive tract or in the course of metabolism in the tissues. This convertible portion of the feed energy has been given various names by different investigators, such as "physiological heat value," "fuel value," "available energy," etc. Without entering here into a discussion of the propriety of these names, we have preferred for our present purpose to follow the suggestion made earlier by the senior author (2, p. 270) and to designate it as "metabolizable energy." By this term is meant simply the energy capable of transformation in the body, with no implications as to the proportion of the energy thus trans-

formed which can be utilized by the organism. The heat evolved during the methane fermentation, for example, constitutes part of the metabolizable energy as thus defined, although it does not enter into the tissue metabolism.

The determination of the losses of chemical energy from a single feeding stuff or from a mixed ration is relatively simple, as is illustrated by the following example taken from the results on steer B in experiment 207.

Computation of losses of chemical energy from a ration

Energy of feed:	Period 2.	Period 3.
Timothy hay.....	12, 477 Cals.	12, 618 Cals.
Grain mixture No. 1.....	12, 549 Cals.	.....
Total	25, 026 Cals.	12, 618 Cals.
Energy of excreta:		
Feces.....	7, 371 Cals.	5, 247 Cals.
Urine.....	1, 536 Cals.	627 Cals.
Methane.....	2, 098 Cals.	1, 057 Cals.
Total.....	11, 005 Cals.	6, 931 Cals.
Metabolizable energy.....	14, 021 Cals.	5, 687 Cals.

Since concentrates can not be fed alone, the losses of chemical energy which they suffer, like their digestibility, must be obtained by means of a calculation by difference, which in period 2 of the foregoing example is as follows:

Computation of losses of chemical energy by a concentrate

	Chemical energy of feed. Calories.	Chemical energy of excreta.			Metabolizable energy. Calories.
		Feces. Calories.	Urine. Calories.	Methane. Calories.	
Total ration.....	25, 026	7, 371	1, 536	2, 098	14, 021
Computed for hay.....	12, 477	5, 254	591	1, 003	5, 629
Grain mixture by difference.....	12, 549	2, 117	945	1, 095	8, 392

Computed in the manner just illustrated, the losses of chemical energy per kilogram of dry matter consumed in these experiments and the metabolizable energy remaining are shown in Table III, which includes also the percentage distribution of the feed energy between the various excreta, on the one hand, and the metabolizable energy, on the other.¹ For convenience, the average results for the metabolizable energy per kilogram of dry matter and per kilogram of digestible organic matter are brought together in Table IV.

¹ In all cases the observed energy of the urine has been corrected to nitrogen equilibrium of the animal by adding 7.5 Calories for each gram of nitrogen retained by the animal or subtracting the same amount for each gram of body nitrogen lost, the correction being regarded as representing energy of excretory material temporarily retained in the body.

TABLE III.—Losses of energy and their percentage distribution

Feeding stuff and experiment No.	Animal No.	Period No.	Dry matter eaten per day and head.		Energy per kilogram of dry matter.						Metabolizable per kilogram of digestible organic matter.	Percentage losses.			Percentage metabolizable.
			Coarse feed.	Concentrates.	Total. ^a	Losses.			Metabolizable.	In feces.		In urine.	In CH ₄ .		
						In feces.	In urine. ^b	In CH ₄ .							
Timothy hay:			Gm.	Gm.	Cals.	Cals.	Cals.	Cals.	Cals.	Cals.					
174 ^c	I	D-A	4,483	356	4,554	2,439	156	285	1,674	3,483	53.56	3.44	6.25	36.75	
190.....	A	3	2,001		4,502	2,209	164	309	1,820	3,429	49.06	3.64	6.87	40.43	
190.....	A	4	3,493		4,488	2,306	128	303	1,751	3,480	51.38	2.86	6.75	39.01	
190.....	B	3	1,774		4,503	2,209	141	342	1,811	3,399	49.07	3.14	7.60	40.20	
190.....	B	4	2,610		4,483	2,176	125	304	1,878	3,484	48.55	2.79	6.78	41.88	
Average..			2,470		4,494	2,225	139	315	1,815	3,448	49.51	3.09	7.01	40.39	
200.....	A	3	2,647		4,510	2,175	155	314	1,866	3,597	48.22	3.44	6.97	41.37	
200.....	A	4	4,425		4,509	2,250	153	301	1,805	3,566	49.91	3.40	6.68	40.01	
200.....	B	3	2,470		4,510	2,092	168	326	1,924	3,565	46.39	3.72	7.24	42.65	
200.....	B	4	3,805		4,509	2,164	167	312	1,866	3,565	48.00	3.70	6.92	41.38	
Average..					4,509	2,170	161	313	1,865	3,573	48.13	3.57	6.94	41.36	
207.....	A	3	2,974		4,509	1,841	204	368	2,096	3,457	40.82	4.52	8.17	46.49	
207.....	A	4	4,892		4,521	1,888	199	357	2,077	3,482	41.77	4.40	7.90	45.93	
207.....	B	3	2,798		4,509	1,875	224	378	2,032	3,378	41.58	4.97	8.38	45.07	
207.....	B	4	4,630		4,521	1,918	208	355	2,040	3,456	42.42	4.61	7.84	45.13	
Average..					4,513	1,880	208	364	2,061	3,443	41.66	4.61	8.07	45.66	
Red-clover hay:															
179.....	I	1	4,459		4,450	1,940	306	309	1,895	3,373	43.61	6.87	6.94	42.58	
179.....	I	2	3,144		4,426	1,857	288	324	1,957	3,452	41.95	6.50	7.33	44.22	
Average..					4,438	1,898	297	317	1,926	3,413	42.77	6.69	7.14	43.40	
186.....	I	1a	2,933		4,490	1,842	326	303	2,019	3,460	41.03	7.25	6.75	44.97	
186.....	I	2a	5,025		4,489	1,817	301	243	2,129	3,637	40.49	6.72	5.41	47.38	
186.....	I	3a	4,139		4,478	1,852	290	254	2,082	3,578	41.36	6.48	5.68	46.48	
Average..					4,486	1,837	306	267	2,076	3,558	40.95	6.82	5.95	46.28	
Mixed hay:															
211.....	D	1	6,204		4,400	2,077	209	285	1,829	3,442	47.20	4.75	6.49	41.56	
211.....	D	4	3,498		4,391	1,837	234	332	1,990	3,406	41.83	5.33	7.54	45.30	
211.....	D	5	1,786		4,390	1,956	255	345	1,834	3,294	44.57	5.80	7.85	41.78	
211.....	G	1	6,092		4,393	1,906	208	300	1,979	3,463	43.39	4.75	6.82	45.04	
211.....	G	4	3,149		4,391	1,878	220	319	1,974	3,420	42.76	5.00	7.27	44.97	
211.....	G	5	1,608		4,390	1,917	238	358	1,877	3,313	43.68	5.41	8.15	42.76	
Average..					4,393	1,929	227	323	1,914	3,390	43.92	5.17	7.35	43.56	
Alfalfa hay:															
208.....	D	1	2,155		4,407	2,124	244	262	1,777	3,529	48.21	5.54	5.93	40.32	
208.....	D	2	1,300		4,407	2,186	266	273	1,682	3,437	49.61	6.03	6.17	38.19	
208.....	E	4	4,170		4,410	2,043	231	241	1,895	3,697	46.33	5.24	5.46	42.97	
208.....	E	5	2,408		4,407	2,105	249	276	1,777	3,518	47.78	5.64	6.26	40.32	
208.....	E	6	1,413		4,406	2,037	248	281	1,840	3,528	46.24	5.63	6.37	41.76	
208.....	C	4	4,744		4,403	2,184	233	218	1,768	3,655	49.61	5.29	4.95	40.15	
208.....	C	5	3,099		4,407	2,066	243	270	1,828	3,594	46.90	5.51	6.12	41.47	
208.....	C	6	2,119		4,406	2,013	250	280	1,863	3,576	45.69	5.68	6.37	42.26	
Average..					4,407	2,095	246	262	1,804	3,567	47.54	5.58	5.94	40.94	

^a From analyses of individual samples for each period, and therefore differ somewhat from the averages of Table I.

^b Corrected to N equilibrium, using Rubner's factor, 7.45 Calories per gram N.

^c Computed by difference.

TABLE III.—Losses of energy and their percentage distribution—Continued

Feeding stuff and experiment No.	Animal No.	Period No.	Dry matter eaten per day and head.		Energy per kilogram of dry matter.						Metabolizable per kilogram of digestible organic matter.	Percentage losses.			Percentage metabolizable.
			Coarse feed.	Concentrates.	Total.	Losses.			Metabolizable.						
						In feces.	In urine.	In CH ₄ .							
Alfalfa hay—Con.	F		Gm.	Gm.	Cals.	Cals.	Cals.	Cals.	Cals.	Cals.					
209.....	F	4	6,174	.....	4,359	2,046	218	248	1,847	3,652	46.95	5.60	5.69	42.36	
209.....	F	5	3,562	.....	4,328	1,961	244	264	1,859	3,588	45.31	5.63	6.11	42.96	
209.....	F	6	2,226	.....	4,328	2,078	246	281	1,723	3,470	48.01	5.67	6.49	39.83	
Average..					4,338	2,028	236	264	1,810	3,570	46.75	5.44	6.09	41.72	
212.....	H	1	6,638	.....	4,354	1,796	275	277	2,006	3,550	41.26	6.31	6.37	46.06	
212.....	H	3	5,320	.....	4,338	1,805	270	283	1,980	3,525	41.60	6.23	6.53	45.64	
212.....	H	5	3,052	.....	4,413	1,642	290	299	2,181	3,729	37.21	6.58	6.78	49.43	
Average..					4,368	1,748	278	286	2,056	3,601	40.02	6.36	6.55	47.07	
Alfalfa meal:															
212.....	H	2	6,671	.....	4,364	1,889	252	250	1,973	3,671	43.29	5.78	5.74	45.19	
212.....	H	4	5,408	.....	4,379	1,897	250	259	1,973	3,646	43.31	5.72	5.93	45.04	
212.....	H	6	3,155	.....	4,379	1,726	270	292	2,091	3,727	39.41	6.18	6.66	47.75	
Average..					4,374	1,838	257	267	2,012	3,681	42.01	5.89	6.11	45.99	
Maize stover:															
210.....	D	1	4,335	.....	4,333	1,860	172	335	1,966	3,488	42.93	3.96	7.74	45.37	
210.....	D	2	3,548	.....	4,327	1,837	185	335	1,970	3,493	42.47	4.27	7.75	45.51	
210.....	D	3	2,563	.....	4,337	1,867	195	354	1,921	3,369	43.06	4.50	8.15	44.29	
Average..					4,332	1,855	184	341	1,952	3,450	42.82	4.24	7.88	45.06	
Maize meal:															
179.....	I	3	3,163	735	4,360	633	441	488	2,798	3,186	14.52	10.12	11.20	64.16	
179.....	I	4	3,186	3,451	4,366	401	167	406	3,392	3,716	9.18	3.83	9.31	77.68	
Average..					4,363	517	304	447	3,095	3,451	11.85	6.97	10.25	70.93	
211.....	G	2	790	1,542	4,526	382	175	509	3,460	3,825	8.45	3.87	11.25	76.43	
211.....	G	3	2,383	4,644	4,508	948	125	372	3,063	3,928	21.04	2.78	8.25	67.93	
Average..					4,517	665	150	441	3,261	3,877	14.74	3.32	9.75	72.19	
Wheat bran:															
190.....	A	1	1,978	1,370	4,545	1,484	230	365	2,466	4,003	32.67	5.06	8.04	54.24	
190.....	A	2	1,996	2,583	4,558	1,440	221	311	2,586	3,982	31.59	4.85	6.82	56.74	
190.....	B	1	1,712	999	4,563	1,500	254	332	2,477	3,951	32.87	5.56	7.28	54.29	
190.....	B	2	1,779	1,803	4,461	1,336	271	340	2,514	3,872	29.96	6.07	7.62	56.35	
Average..					4,532	1,440	244	337	2,511	3,954	31.77	5.38	7.44	55.41	
Grain mixture No. 1:															
200.....	A	1	2,608	1,792	4,698	611	358	390	3,339	3,946	13.00	7.62	8.30	71.08	
200.....	A	2	2,631	4,173	4,695	1,051	288	358	2,998	3,974	22.38	6.13	7.63	63.86	
200.....	B	1	2,433	1,195	4,697	639	385	381	3,294	3,923	13.60	8.19	8.11	70.10	
200.....	B	2	2,454	2,129	4,695	1,064	322	343	2,966	3,998	22.66	6.86	7.30	63.18	
Average..					4,696	841	338	368	3,149	3,960	17.91	7.20	7.84	67.05	
207.....	A	1	2,935	1,996	4,658	951	316	397	2,994	3,876	20.42	6.78	8.52	64.28	
207.....	A	2	2,949	4,759	4,688	1,019	294	342	3,033	3,991	21.73	6.28	7.29	64.70	
207.....	B	1	2,761	1,398	4,658	1,104	363	439	2,752	3,683	23.71	7.79	9.42	59.08	
207.....	B	2	2,774	2,677	4,688	791	353	409	3,135	3,888	16.87	7.53	8.72	66.88	
Average..					4,673	966	332	397	2,978	3,860	20.68	7.09	8.48	63.75	

* Computed from digestible carbohydrates.

TABLE III.—Losses of energy and their percentage distribution—Continued

Feeding stuff and experiment No.	Animal No.	Period No.	Dry matter eaten per day and head.		Energy per kilogram of dry matter.						Metabolizable per kilogram of digestible organic matter.	Percentage losses.			Percentage metabolizable.
			Coarse feed.	Concentrates.	Total.	Losses.			Metabolizable.	In feces.		In urine.	In CH ₄ .		
						In feces.	In urine.	In CH ₄ .							
Grain mixture No. 2:			Gm.	Gm.	Cals.	Cals.	Cals.	Cals.	Cals.	Cals.					
208.....	F	1	1,086	2,122	4,607	1,258	173	349	2,827	3,887	27.32	3.75	7.58	61.36	
208.....	F	2	590	1,163	4,611	840	202	442	3,127	3,837	18.22	4.38	9.57	67.83	
208.....	F	3	387	764	4,595	901	236	346	3,112	3,890	19.61	5.14	7.54	67.72	
208.....	F	4	731	1,453	4,611	1,246	192	463	2,710	3,706	27.03	4.16	10.04	58.77	
208.....	F	5	521	1,018	4,594	826	242	486	3,038	3,711	17.98	5.28	10.58	66.16	
Average..					4,604	1,014	209	417	2,964	3,806	22.03	4.54	9.06	64.37	
209.....	F	1	1,462	3,040	4,629	1,312	170	283	2,864	3,979	28.35	3.68	6.11	61.86	
209.....	F	2	894	1,862	4,605	1,032	184	327	3,062	3,980	22.40	3.99	7.10	66.51	
209.....	F	3	536	1,112	4,604	891	223	376	3,114	3,896	19.36	4.85	8.16	67.63	
Average..					4,613	1,078	193	329	3,013	3,952	23.37	4.17	7.12	65.34	
Hominy chop:															
211.....	D	2	1,747	1,764	4,720	542	195	496	3,487	3,993	11.48	4.13	10.50	73.89	
211.....	D	3	3,910	3,949	4,698	603	167	371	3,557	4,156	12.83	3.56	7.90	75.71	
Average..					4,709	573	181	433	3,522	4,075	12.15	3.84	9.20	74.81	
Alfalfa hay and grain mixture No. 2:															
208.....	E	1	1,086	2,122	4,531	1,526	195	318	2,492	3,810	33.69	4.30	7.01	55.00	
208.....	E	2	590	1,163	4,535	1,247	214	380	2,694	3,777	27.50	4.72	8.37	59.41	
208.....	E	3	387	764	4,532	1,291	237	316	2,688	3,824	28.49	5.23	6.98	59.30	
208.....	E	4	731	1,453	4,543	1,536	208	390	2,409	3,687	33.81	4.58	8.61	53.00	
208.....	E	5	521	1,018	4,536	1,264	242	406	2,624	3,696	27.86	5.33	8.95	57.86	
Average..					4,535	1,373	219	362	2,581	3,759	30.27	4.83	7.98	56.92	
209.....	F	1	1,462	3,040	4,527	1,540	189	275	2,523	3,872	34.67	4.26	6.18	54.89	
209.....	F	2	894	1,862	4,516	1,352	199	305	2,660	3,888	29.94	4.40	6.74	58.92	
209.....	F	3	536	1,112	4,515	1,259	225	338	2,693	3,826	27.88	4.99	7.48	59.65	
Average..					4,519	1,384	204	306	2,625	3,862	30.62	4.51	6.77	58.09	
Mixed hay and maize meal:															
211.....	G	2	790	1,542	4,483	897	189	443	2,954	3,701	20.00	4.22	9.88	65.90	
211.....	G	3	2,383	4,644	4,468	1,271	156	352	2,689	3,763	28.45	3.49	7.88	60.18	
Average..					4,476	1,084	173	398	2,821	3,732	24.22	3.87	8.89	63.02	
Mixed hay and hominy chop:															
211.....	D	2	1,747	1,764	4,560	1,261	209	403	2,687	3,775	27.65	4.58	8.84	58.93	
211.....	D	3	3,910	3,949	4,553	1,293	196	340	2,724	3,879	28.40	4.30	7.47	59.83	
Average..					4,557	1,277	203	371	2,706	3,827	28.02	4.44	8.15	59.39	

TABLE IV.—Average losses of chemical energy—metabolizable energy

Kind of feed and experiment No.	Gross energy per kilogram of dry matter.	Losses of chemical energy per kilogram of dry matter.	Metabolizable energy.	
			Per kilo-gram of dry matter.	Per kilo-gram of di-gestible or-ganic matter.
Timothy hay:	Calories.	Calories.	Calories.	Calories.
174.....	4,554	2,880	1,674	3,483
190.....	4,494	2,679	1,815	3,448
200.....	4,509	2,644	1,865	3,573
207.....	4,513	2,452	2,061	3,443
Average.....	4,518	2,664	1,854	3,487
Red clover hay:				
179.....	4,438	2,512	1,926	3,413
186.....	4,486	2,410	2,076	3,558
Average.....	4,462	2,461	2,001	3,486
Mixed hay:				
211.....	4,393	2,479	1,914	3,390
Alfalfa hay:				
208.....	4,407	2,603	1,804	3,567
209.....	4,338	2,528	1,810	3,570
212.....	4,368	2,312	2,056	3,601
Average.....	4,371	2,481	1,890	3,579
Alfalfa meal:				
212.....	4,374	2,362	2,012	3,681
Average of alfalfa hay and meal.	4,372	2,451	1,921	3,605
Maize stover:				
210.....	4,332	2,380	1,952	3,450
Maize meal:				
179 ^a	4,366	974	3,392	3,716
211.....	4,517	1,256	3,261	3,877
Average.....	4,442	1,115	3,327	3,797
Wheat bran:				
190.....	4,532	2,021	2,511	3,954
Grain mixture No. 1:				
200.....	4,696	1,547	3,149	3,960
207.....	4,673	1,695	2,978	3,860
Average.....	4,685	1,621	3,064	3,910
Grain mixture No. 2:				
208.....	4,604	1,640	2,964	3,806
209.....	4,613	1,600	3,013	3,952
Average.....	4,609	1,620	2,989	3,879
Hominy chop:				
211.....	4,709	1,187	3,522	4,075

^a Period 4.

The results recorded in Table III illustrate the familiar fact that the greatest loss of chemical energy, especially in the case of coarse feeds, is that in the undigested feed residues of the feces and in the relatively small amounts of excretory products which, in the case of cattle, accompany them. The relative proportions lost in the urine and in the methane naturally vary with the composition of the feed, one rich in protein tending especially to increase the energy content of the urine, while carbohydrates tend to increase the excretion of methane.

Of greater interest, however, is the variability of the losses suffered by the same feeding stuff in different periods.

INFLUENCE OF QUANTITY OF FEED CONSUMED ON LOSSES OF CHEMICAL ENERGY

In considering this question it should be borne in mind that the comparisons here reported are in every instance between *different amounts of the same ration*—i. e., they deal with the influence of quantity only and do not touch the question of the influence of heavy grain feeding. Furthermore, they relate to comparatively light feeding, many of the periods having been upon submaintenance rations, while the total dry matter of the feed seldom reached 18 pounds per 1,000 pounds of live weight. The experiments recorded in Table III include 31 cases in which different amounts either of a single feeding stuff or of an identical mixed ration were consumed by the same animal in two different periods of the same experiment, under conditions as nearly uniform as it was possible to make them. The results may be most conveniently compared on the basis of the percentage distribution of the energy, as shown in the last four columns of the table. In the following comparisons the results computed by difference for the concentrated feeds are not included.

LOSSES IN METHANE

In a single instance (alfalfa hay and grain mixture No. 2 in experiment 208, steer E, periods 2 and 3) the percentage loss in the methane was greater on the heavier of the two rations and in another case (corn stover in experiment 210, steer D, periods 1 and 2) the difference was only 0.01 per cent. In two cases the determinations of methane are believed to have been inaccurate. In the remaining 29 cases the percentage loss in methane was distinctly greater on the lighter ration, the difference ranging from 0.11 to 2 per cent and tending, on the whole, to be somewhat greater on the mixed rations, with their larger proportion of readily soluble carbohydrates, than on those consisting exclusively of coarse fodder. In other words, as would be anticipated, the bacterial fermentation of the carbohydrates in the digestive tract of cattle proceeds to a distinctly greater extent on light than on heavy rations.

LOSSES IN URINE

The percentage of the feed energy excreted in the urine was also greater on the lighter ration in 28 cases out of 33, the exceptions being two experiments on alfalfa hay (experiment 208, steer E, periods 5 and 6,

and experiment 212, steer H, periods 1 and 3), two on clover hay (experiment 179, steer I, periods 1 and 2, and experiment 186, steer I, periods 2a and 3a), and one on alfalfa meal (experiment 212, steer H, periods 2 and 4). In the remaining 28 cases there is one in which the difference amounts to only 0.02 per cent and two in which it is 0.04 per cent. In the remaining 25 it ranges from 0.12 to 0.78 per cent. This greater relative loss in the urine on the lighter ration can not be attributed to the presence of nitrogenous substances derived from an increased katabolism of body protein, since the energy of the urine has been at least approximately corrected to nitrogen equilibrium (p. 440). Since it is well established that the urine of cattle contains a considerable quantity of nonnitrogenous substances (2, p. 312-314, 320-322), it seems not impossible that the more extensive fermentation on the lighter ration may have resulted in an increase of these unknown constituents.

LOSSES IN FECES

The results regarding the losses of chemical energy in the feces are by no means so uniform as in the case of the methane and of the urine. In 22 out of 33 cases there is a distinctly smaller relative loss of energy in the feces with the lighter ration—i. e., a greater apparent digestibility—the difference in the percentages ranging from 0.28 to 8.45. In the other third of the cases, however, the difference is in the opposite direction, ranging from 0.37 to 2.74, with the exception of one case of practical equality, so that it appears that other factors besides the extent of the methane fermentation affected the percentage digestibility. Two rather marked cases of a greater loss of energy in the feces on the lighter ration are found in experiment 211, periods 4 and 5, with relatively very small rations. Whether the relative loss in the feces increases or decreases with an increase of the ration seems to bear no relation to the total quantity of feed consumed either per head or per 500 kg. of live weight. The 10 instances in which a greater percentage loss in the feces was observed on the lighter of the two rations include, it is true, the more extreme rations as regards the total quantity, but the averages for the two groups are not widely different (4,376 and 3,952 gm. of dry matter).

PERCENTAGE OF FEED ENERGY METABOLIZABLE

The bearing of the foregoing facts upon the percentage of the feed energy which is metabolizable is obvious. Clearly the fermentation which plays so large a rôle in the digestive processes of ruminants was relatively more intense on the lighter rations, resulting in the breaking down of a larger proportion of the carbohydrates and in a greater loss of chemical energy in the methane, accompanied in most instances by an increased loss in the urine also. On the other hand, however, the organic acids resulting from the fermentation are resorbed and oxidized in the body, and their energy, together with the heat evolved in the fermentation, constitutes part of the metabolizable energy of the feed as defined on page 439. Whether the proportion of the total energy of the feed which is metabolizable be greater or less on the lighter ration will depend, therefore, upon the nature of the additional carbohydrates fermented. If the increased fermentation attacks the more insoluble carbohydrates, which would otherwise escape digestion entirely and

reappear in the feces, the result will be a relative increase in the metabolizable energy. On the other hand, if the greater fermentation on the lighter rations is at the expense of the more soluble carbohydrates which would otherwise be digested by the enzymes of the intestines, the metabolizable energy will be diminished by the quantity of chemical energy escaping in the methane (and urine). It is perhaps not surprising, therefore, to find that the effect of the quantity of feed upon the percentage of energy metabolizable was somewhat variable.

In 19 out of 22 cases mentioned in the previous paragraph in which the percentage loss of energy in the feces decreased as the amount of feed consumed was diminished, the percentage of energy metabolized did in fact increase, while in the remaining 3 cases the greater losses in methane and urine overbalanced the effect of the increased digestibility. In each of the 10 instances in which the percentage loss of energy in the feces was greater on the lighter rations, the percentage metabolizable shows a corresponding decrease, so that of the entire 33 comparisons 14 show a greater and 19 a less percentage metabolizable on lighter as compared with heavier rations.

On the whole, then, the differences in amount of feed consumed, within the limits of these experiments, failed to show any unmistakable effect upon the quantity of energy actually liberated in the body from a unit weight of feed. Moreover, it must be borne in mind that a considerable part of the additional energy secured by the more extensive fermentation of the lighter ration is liberated in the digestive tract as heat of fermentation and does not enter into the energy exchange of the body tissues, so that the difference in the net nutritive effect is likely to be less than that in the metabolizable energy as ordinarily defined.

INFLUENCE OF INDIVIDUALITY ON LOSSES OF CHEMICAL ENERGY

In five of the experiments the same feeding stuff or mixture of feeding stuffs was fed to more than one animal, although unfortunately the amounts consumed were not the same either per head or in proportion to the live weight, so that exact comparisons are not possible.

In experiments 190, 200, and 207 a pure-bred Shorthorn steer was compared with a so-called scrub. A comparison of the averages for the lighter and the heavier rations of timothy hay, respectively, for the three successive years gives the averages shown in Table V, which fail to show any distinct individual difference between the two animals. The results computed by difference for the wheat bran in experiment 190 and for the grain mixture No. 1 in experiments 200 and 207 show somewhat larger numerical differences, but when the errors incident to such calculations by difference are considered they agree with those upon hay in showing no material difference between these two animals. This point has been discussed from a slightly different standpoint elsewhere (10).

TABLE V.—Influence of individuality of cattle on losses of chemical energy

Character of experiment.	Loss of energy.			Metabolizable.
	In feces.	In urine.	In methane.	
Timothy hay (experiments 190, 200, and 207):				
Average of light rations—	Per cent.	Per cent.	Per cent.	Per cent.
Steer A.....	46.03	3.87	7.34	42.76
Steer B.....	46.03	3.96	7.79	42.22
Difference.....	0	-.09	-.45	+.54
Average of heavy rations—				
Steer A.....	47.69	3.55	7.11	41.65
Steer B.....	46.32	3.70	7.18	42.80
Difference.....	+ 1.37	-.15	-.07	- 1.15
Average of all rations—				
Steer A.....	46.86	3.71	7.22	42.21
Steer B.....	46.18	3.83	7.49	42.50
Difference.....	+ .68	-.12	-.27	-.29
Alfalfa hay (experiment 208):				
Average of medium and light rations—				
Steer D (periods 1 and 2).....	48.91	5.79	6.05	39.25
Steer E (periods 5 and 6).....	47.01	5.64	6.31	41.04
Steer C (periods 5 and 6).....	46.30	5.60	6.24	41.86
Difference (D-C).....	+ 2.61	+.19	-.19	- 2.61
Heavy rations—				
Steer E (period 4).....	46.33	5.24	5.46	42.97
Steer C (period 4).....	49.61	5.29	4.95	40.15
Difference.....	- 3.28	-.05	+.51	+ 2.82
Alfalfa hay and grain (experiment 208):				
Average of medium and light rations—				
Steer E (periods 2 and 3).....	28.00	4.98	7.67	59.35
Steer C (periods 2 and 3).....	30.83	4.96	8.78	55.43
Difference.....	- 2.83	+.02	-1.11	+ 3.92
Mixed hay (experiment 211):				
Steer D (periods 1, 4, and 5)....	44.53	5.29	7.30	42.88
Steer G (periods 1, 4, and 5)....	43.28	5.05	7.41	44.26
Difference.....	+ 1.25	+.24	-.11	- 1.38

The three animals used in experiment 208 had been subjected to different previous treatment, steer D having received almost from birth a restricted quantity of feed, steer E a ration ample to support normal growth, and steer C as heavy feeding as practicable. In the periods on the medium and light rations of alfalfa hay these animals showed slight differences in their digestive powers in the order named, the average

results for the two quantities being as shown in Table V. On the other hand, upon the heavy hay ration and also upon the mixed ration of hay and grain steer C was distinctly inferior to steer E, losing more chemical energy in both methane and feces. This was the most distinct individual difference in these experiments. It should perhaps be noted that steer C showed a tendency to bloat and to get off feed on heavy rations and possibly did not have full normal digestive power. In experiment 211 steer D, then a year older, on the average of three periods on mixed hay again showed a slight inferiority to another animal which presumably had received better feeding during growth.

Clearly individual differences between the animals had no very material influence on the losses of chemical energy in these experiments. In most instances the differences are well within the limits of error for such determinations, and even in those cases where there seem to be distinct individual differences they are comparatively slight, being of about the same magnitude as those observed by G. Kühn (28) and rather smaller than those found by Armsby (1) in experiments on three steers.

VARIABILITY OF METABOLIZABLE ENERGY

The results recorded in Tables III and IV show clearly that the metabolizable energy of a feeding stuff is by no means a constant. Not only do the averages for feeding stuffs of the same name differ more or less, but the metabolizable energy of the same sample is more or less variable in the different periods.

The losses of chemical energy which a feeding stuff suffers are substantially determined by the nature and extent of the digestive processes. Digestibility, however, especially in ruminants, is a very complex affair, depending on many factors. Broadly speaking, it may be characterized as a series of fermentations, effected in part by a variety of organized ferments and in part by enzymes secreted by the digestive organs or contained in the feed itself. Changes in the composition of the contents of the digestive tract or in the rapidity with which they move forward through it can hardly fail to influence in a variety of ways the course of these fermentations, and it seems on the whole rather surprising that they go forward as uniformly as they do.

In these experiments they appear to have been affected chiefly by the variations in the amount of feed consumed. Recently Zuntz and his associates (20, 53) have reported striking instances in which the extent of the methane fermentation in particular has been markedly affected by the make-up of the rations and especially by the order in which the feeds were consumed, while Völtz and his associates (47, 48) have laid much stress on the practical importance of these results. No such marked differences occurred in our experiments, but, on the other hand, the range of feeds was not so wide. It is perhaps too early

to judge the full significance of Zuntz's results, but they should at least serve to correct the notion, more or less subconsciously held by not a few, of digestion as a perfectly definite process and of a digestion coefficient as a sort of chemical constant. On the other hand, however, it is easy to overestimate the importance of these variations in the digestive process in their bearing upon estimates of the values of feeding stuffs. On the whole, they appear to be of far less significance than other factors to be considered later.

ESTIMATION OF METABOLIZABLE ENERGY

FROM METABOLISM EXPERIMENTS

The losses of chemical energy in feces and urine are readily determined by means of the ordinary metabolism experiment, but the determination of the losses in the combustible gases requires special and somewhat costly apparatus. A number of experimenters have therefore attempted to estimate the amounts of these gases produced, usually from the amounts of carbohydrates (crude fiber and nitrogen-free extract) digested, using, as a rule, the average factor derived from Kellner's investigations (26, p. 420)—viz, 4.2 parts of CH_4 per 100 parts of digested carbohydrates.

Our experiments have yielded somewhat higher figures, as shown in Table VI, giving the maximum, minimum, and average results for each feeding stuff or mixture.

TABLE VI.—Quantity of methane per 100 gm. of digestible carbohydrates

Feeding stuff.	Number of experiments.	Quantity of methane.		
		Maximum.	Minimum.	Average.
		Gm.	Gm.	Gm.
Timothy hay.....	12	3.8	5.1	4.6
Clover hay.....	5	3.9	5.2	4.6
Mixed hay.....	6	4.6	5.8	5.1
Alfalfa hay.....	17	4.2	5.3	4.8
Maize stover.....	3	4.7	4.8	4.7
Average.....	43			4.8
Maize meal and clover hay.....	2	4.3	5.2	4.8
Wheat bran and timothy hay.....	4	4.8	5.2	4.9
Grain mixture No. 1 and timothy hay.....	4	4.7	5.3	5.0
Grain mixture No. 2 and alfalfa hay.....	8	3.8	5.5	4.5
Maize meal and mixed hay.....	2	4.2	4.7	4.5
Hominy chop and mixed hay.....	2	4.4	5.0	4.7
Average.....	22			4.7
Average of author's experiments.....	65	3.8	5.5	4.8
Average of Kellner's experiments.....	44	2.9	5.5	4.2

While there is a considerable range in the results of individual experiments, nevertheless an estimate of 4.5 grams of CH_4 per 100 gm. of digested carbohydrates affords a fair basis for an approximate estimate of the losses of chemical energy in the combustible gases and for computing the metabolizable energy of a feeding stuff by means of the ordinary digestion experiment combined with the collection of the urine and a determination of the heats of combustion of the visible excreta. The additional labor required for this purpose is so small that it is to be hoped that in future digestion experiments it may be undertaken whenever possible.

FROM DIGESTIBLE ORGANIC MATTER

It is possible also to estimate the average metabolizable energy of a feeding stuff from its content of total digestible organic matter, as shown by the ordinary feeding tables.

The differences shown in Tables III and IV between the metabolizable energy per kilogram of dry matter of the different feeding stuffs are due chiefly, as already pointed out, to differences in the proportion of the chemical energy carried off in the feces, so that the metabolizable energy per kilogram of digestible organic matter shows a striking degree of uniformity as between different coarse feeds, on one hand, and as between different concentrates, on the other, a fact quite in harmony with earlier results reported by Kellner (26). Expressing the results in therms per kilogram and using for the apparent metabolizable energy of Kellner and Köhler's feeding stuffs the figures computed by Armsby (2, p. 301), we obtain the following averages:

Metabolizable energy per kilogram of digestible organic matter

COARSE FEEDS		Therms.
Armsby and Fries:		
Timothy hay.....		3.49
Red clover hay.....		3.49
Mixed hay.....		3.39
Alfalfa hay and meal.....		3.61
Maize stover.....		3.45
Average.....		3.48
Kellner and Köhler:		
Meadow hay.....		3.50
Oat straw.....		3.74
Wheat straw.....		3.31
Extracted straw.....		3.64
Average.....		3.55

CONCENTRATES

	Therms.
Armsby and Fries:	
Maize meal.....	3.80
Wheat bran.....	3.99
Grain mixture No. 2.....	3.88
Average.....	3.89
Grain mixture No. 1.....	3.91
Hominy chop.....	4.08
Average.....	4.00
Kellner and Köhler:	
Beet molasses.....	3.47
Starch.....	3.60
Wheat gluten.....	4.79

Tangl (44), Tangl and Weiser (45), and Zaitschek (50) have also determined the metabolizable energy of a number of feeding stuffs for cattle, the methane being estimated from the amount of digestible carbohydrates, with the following results, which are very similar to those just reported:

Metabolizable energy per kilogram of digestible organic matter: Tangl's experiments

	Therms.
Meadow hay.....	3.44
Ensiled meadow hay.....	3.70
Hay from irrigated meadows.....	3.60
Broom-corn millet meal.....	3.68
Pumpkins.....	4.29

On the other hand, four experiments upon a bull by Völtz et al. (48), in which the production of methane was likewise computed, gave notably higher figures, viz:

Metabolizable energy per kilogram of digestible organic matter: Völtz's experiments

	Therms.
Mixed ration (hay, straw, malt sprouts, dried brewers' grains, and potato flakes).....	3.95
Dried distillery residue (from potatoes).....	4.84
Palm-nut meal.....	4.85
Beet molasses.....	4.36

The most important factor influencing the metabolizable energy of the digestible organic matter of concentrates seems to be the percentage of fat in the feeding stuff, as appears from a comparison of the data contained in Table I, while feeding stuffs exceptionally high in protein have also a high content of metabolizable energy in their digestible matter, as in the case of Kellner and Köhler's wheat gluten. There seems no obvious explanation of the exceptionally high results obtained by Völtz, but it would seem that for the present, with the ordinary dry feeding stuffs or mixtures, the following factors may safely be made the basis for computing approximately the metabolizable energy of feeding stuffs for cattle when their content of digestible organic matter is known or can be estimated.

Metabolizable energy of feeding stuffs per kilogram of digestible organic matter

	Therms.
Coarse feeds.....	3.5
Concentrated feeds:	
With less than 5 per cent of digestible fat.....	3.9
With more than 5 per cent of digestible fat.....	4.0

No similar results have been reported on succulent feeds, with the exception of Zaitschek's figure for pumpkins.

II. EXPENDITURE OF ENERGY CONSEQUENT UPON FEED CONSUMPTION AND ITS FACTORS

That the consumption of feed tends to increase the metabolism of an animal has become a commonplace of physiology. The magnitude of the effect varies within rather wide limits according to the chemical and physical properties of the feed, while there is still more or less difference of opinion as to its causes. Zuntz and his associates have called it "work of digestion" and have attributed it largely to increased muscular and glandular activity of the digestive and excretory organs. Most physiological investigations in this field have been made on carnivora or on man, in which the increase of the metabolism is not usually very large, except when much protein is consumed. More recent investigations on these species appear to have shown that the mechanical work of the digestive organs is but a small factor and that the term "work of digestion" is not a fortunate one. With herbivora and especially with ruminants, however, the total effect on the metabolism is quantitatively very marked, while the mechanical factor is of much greater significance. This was early shown by Zuntz and Hagemann (52) in their investigations upon the horse. With ruminants the most extensive investigations are those made at the Möckern (Germany) Experiment Station by G. Kühn (29) and by Kellner (24, 25, 26, 27). These investigations, especially those of Kellner, were directed primarily to the determination of the relative values of nutrients and feeding stuffs, but from another point of view they constituted also determinations of the energy expenditure caused by the feed. The main purpose of the experiments here reported was to determine the proportion of the feed energy expended in the increased metabolism by means of direct measurements of the heat evolved, checked by determinations of the respiratory products, the relative values of the feeding stuffs being obtained by difference.

DIFFERENCES IN MUSCULAR ACTIVITY

INFLUENCE OF STANDING OR LYING UPON METABOLISM

We have repeatedly called attention to the very striking increase in the heat elimination of cattle when standing as compared with that when lying and have shown (11), in reply to the criticism of Zuntz, that it is

accompanied by a substantially corresponding increase in the gaseous excretion.

Since conclusions regarding the influence of feed consumption on the heat production must be drawn from comparisons of two or more periods on different amounts of feed, it is obvious that the periods must be made as nearly identical in other respects as practicable. It being impossible to control the standing and lying of the subject, it became necessary, therefore, to attempt a quantitative determination of the influence of standing upon the metabolism of the animal as measured by its heat production and on this basis to correct the results of each period to some uniform ratio of standing to lying. It was natural to suppose that the increment of the metabolism during standing was due to the work of supporting the body in an upright position, but it soon became evident that it was also to a very considerable extent a function of the feed consumption.

The apparatus used in these experiments is a flow calorimeter, the temperature difference between the ingoing and the outgoing water being read every four minutes. Since the hydrothermal equivalent of the absorber system and the contained water is only 6 kg., it is possible to follow very closely the rate of elimination of heat by radiation and conduction. The results found by the authors (11) show that the heat carried off as latent heat of water vapor is substantially proportional to that eliminated by radiation and conduction. On this basis the average heat elimination per minute and for 24 hours during standing and lying has been computed for each 48-hour period (or, in experiments 174, 190, 200, and 207, from selected uniform intervals). The addition of the necessary correction for the gain or loss of matter by the body gives the average heat production when standing or lying, respectively, while the difference between the two represents the increment due to standing for 24 hours. The following example, taken from experiment 179, period 1, in which 76.65 per cent of the total heat emitted was given off by radiation and conduction and 23.35 per cent as latent heat of water vapor, and in which the correction for loss of matter by the body was -127 Calories, may serve to illustrate the method.

Method of computing heat production of cattle when standing or lying

	Standing.	Lying.
Time standing or lying	minutes.. 1,767	1,113
Heat emitted by radiation and conduction:		
Total	Calories.. 12,652	5,128
Per minute	Calories.. 7.160	4.607
Total heat production computed per 24 hours:		
Standing	$7.160 \times 1,440 + 0.7665 - 127 = 13,324$	Calories.
Lying	$4.607 \times 1,440 + 0.7665 - 127 = 8,528$	Calories.
Difference	4,796	Calories.

The differences thus found between the heat production of the animals per 24 hours when standing and when lying were as shown in Table VII, in which are included for comparison the total dry matter consumed and the average live weight of the animal. In order to facilitate a general comparison of the results of the several experiments, the influence of the differences in live weight has also been eliminated to a degree by computing the data of Table V to a uniform body weight of 500 kg., with the results shown graphically in figure 1.

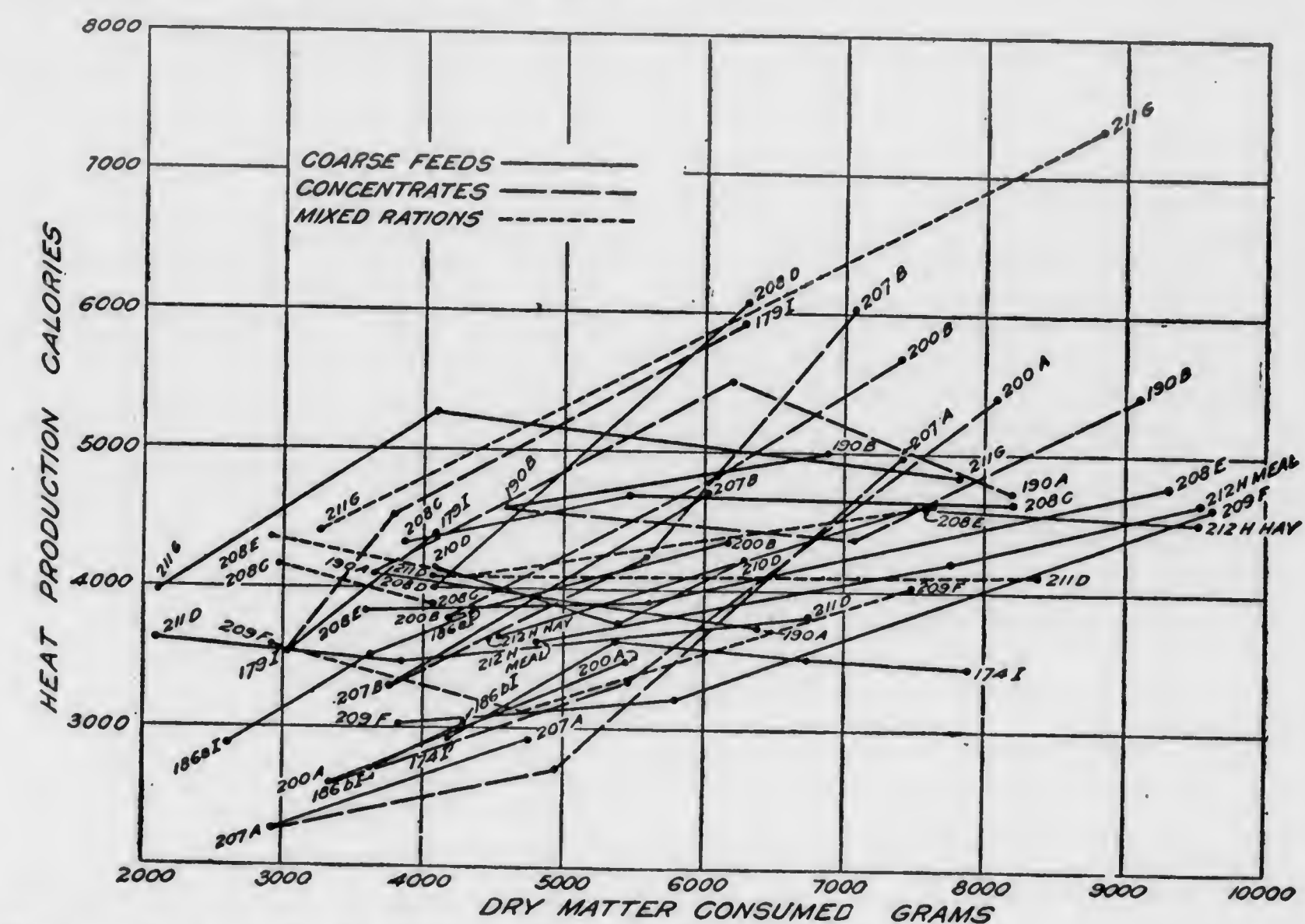


FIG. 1.—Graph showing the dry matter eaten and the increments of heat production due to standing; computed per 500 kg. live weight per 24 hours.

It should be clearly understood that both Table VII and figure 1 show the relation of feed consumption to the *heat increment during standing*, computed in the manner just illustrated, and not to the total heat production.

TABLE VII.—Increments of heat production of cattle in standing

Feeding stuff and experiment.	Average live weight.	Dry matter eaten per head.	Increment of heat production per 24 hours.	
			Per head.	Per kilogram of increment of dry matter eaten.
TIMOTHY HAY:				
Experiment 174—	Kilograms.	Grams.	Calories.	Calories.
Steer I (period A).....	387	3, 237	2, 258	598 —20 16 210
Steer I (period B).....	403	4, 373	2, 935	
Steer I (period C).....	416	5, 480	2, 913	
Steer I (period D).....	424	6, 440	2, 928	
Steer I (periods D-A).....				
Experiment 190—				
Steer A (period 3).....	269	2, 001	2, 206	—88 148
Steer A (period 4).....	278	3, 493	2, 076	
Steer B (period 3).....	194	1, 774	1, 774	
Steer B (period 4).....	190	2, 610	1, 899	
Experiment 200—				
Steer A (period 3).....	399	2, 647	2, 052	442 346
Steer A (period 4).....	407	4, 425	2, 838	
Steer B (period 3).....	296	2, 470	2, 233	
Steer B (period 4).....	309	3, 805	2, 695	
Experiment 207—				
Steer A (period 3).....	507	2, 974	2, 293	364 628
Steer A (period 4).....	514	4, 892	2, 994	
Steer B (period 3).....	374	2, 798	2, 467	
Steer B (period 4).....	385	4, 630	3, 618	
RED CLOVER HAY:				
Experiment 179—				
Steer I (period 1).....	545	4, 459	4, 794	848
Steer I (period 2).....	520	3, 144	3, 679	
Experiment 186 (series a)—				
Steer I (period 1).....	571	2, 933	3, 247	637 474 570
Steer I (period 3).....	580	4, 139	4, 018	
Steer I (period 2).....	587	5, 025	4, 438	
Steer I (periods 2-1).....				
Experiment 186 (series b)—				
Steer I (period 3).....	566	4, 139	3, 080	420
Steer I (period 2).....	576	5, 025	3, 452	
MIXED HAY:				
Experiment 211—				
Steer D (period 1).....	460	6, 204	3, 515	136 24 92
Steer D (period 4).....	455	3, 498	3, 147	
Steer D (period 5).....	428	1, 786	3, 107	
Steer D (periods 1-5).....				
Steer G (period 1).....	389	6, 092	3, 764	—102 764 196
Steer G (period 4).....	387	3, 149	4, 066	
Steer G (period 5).....	364	1, 608	2, 887	
Steer G (periods 1-5).....				
ALFALFA HAY:				
Experiment 208—				
Steer D (period 1).....	171	2, 155	2, 077	894 264 170
Steer D (period 2).....	162	1, 300	1, 314	
Steer E (period 4).....	224	4, 170	2, 145	
Steer E (period 5).....	215	2, 408	1, 683	
Steer E (period 6).....	197	1, 413	1, 512	230 18 286 118
Steer E (periods 4-6).....				
Steer C (period 4).....	289	4, 744	2, 690	
Steer C (period 5).....	284	3, 099	2, 659	
Steer C (period 6).....	275	2, 119	2, 380	
Steer C (periods 4-6).....				

TABLE VII.—Increments of heat production of cattle in standing—Continued

Feeding stuff and experiment.	Average live weight.	Dry matter eaten per head.	Increment of heat production per 24 hours.	
			Per head.	Per kilogram of increment of dry matter eaten.
ALFALFA HAY—Continued.				
Experiment 209—	Kilograms.	Grams.	Calories.	Calories.
Steer F (period 4).....	321	6,174	2,973	} 372 172
Steer F (period 5).....	308	3,562	1,997	
Steer F (period 6).....	292	2,226	1,768	
Steer F (periods 4-6).....				
Experiment 212—				304
Steer H (period 1).....	349	6,638	3,167	} -44 328
Steer H (period 3).....	354	5,320	3,224	
Steer H (period 5).....	337	3,052	2,481	
Steer H (periods 1-5).....				
ALFALFA MEAL:				192
Experiment 212—				
Steer H (period 2).....	349	6,671	3,246	} 242 252
Steer H (period 4).....	349	5,408	2,942	
Steer H (period 6).....	329	3,155	2,377	
Steer H (periods 2-6).....				
MAIZE STOVER:				248
Experiment 210—				
Steer D (period 1).....	345	4,335	2,919	} 550 -134
Steer D (period 2).....	331	3,548	2,486	
Steer D (period 3).....	316	2,563	2,617	
Steer D (periods 1-3).....				
MAIZE MEAL ADDED TO CLOVER HAY:				170
Experiment 179—				
Steer I (period 2).....	520	^a 3,144	3,679	} 1,300 598
Steer I (period 3).....	514	3,898	4,659	
Steer I (period 4).....	532	6,637	6,296	
Steer I (periods 4-2).....				
WHEAT BRAN ADDED TO TIMOTHY HAY:				748
Experiment 190—				
Steer A (period 3).....	269	^a 2,001	2,206	} 586 -288
Steer A (period 1).....	271	3,348	2,995	
Steer A (period 2).....	279	4,579	2,639	
Steer A (periods 2-3).....				
Steer B (period 3).....	194	^a 1,774	1,774	} -32 540
Steer B (period 1).....	199	2,803	1,741	
Steer B (period 2).....	197	3,582	2,135	
Steer B (periods 2-3).....				
GRAIN MIXTURE NO. 1 ADDED TO TIMOTHY HAY:				200
Experiment 200—				
Steer A (periods 3).....	399	^a 2,647	2,052	} 374 765
Steer A (period 1).....	404	4,400	2,708	
Steer A (period 2).....	421	6,804	4,547	
Steer A (periods 2-3).....				
Steer B (period 3).....	296	^a 2,470	2,233	} 600 565 736
Steer B (period 1).....	298	3,628	2,887	
Steer B (period 2).....	310	4,583	3,591	
Steer B (periods 2-3).....				
				642

^a Basal ration of coarse fodder only.

TABLE VII.—Increments of heat production of cattle in standing—Continued

Feeding stuff and experiment.	Average live weight.	Dry matter eaten per head.	Increment of heat production per 24 hours.	
			Per head.	Per kilogram of increment of dry matter eaten.
GRAIN MIXTURE NO. 1 ADDED TO TIMOTHY HAY—Continued.				
Experiment 207—	Kilograms.	Grams.	Calories.	Calories.
Steer A (period 3).....	507	^a 2,974	2,293	210 892
Steer A (period 1).....	499	4,931	2,704	
Steer A (period 2).....	519	7,708	5,182	
Steer A (periods 2-3).....				610
Steer B (period 3).....	374	^a 2,798	2,467	513 1,158 828
Steer B (period 1).....	373	4,159	3,165	
Steer B (period 2).....	386	5,451	4,659	
Steer B (periods 2-3).....				
ALFALFA HAY AND GRAIN MIXTURE No. 2:				
Experiment 208—				
Steer E (period 1).....	210	3,208	1,944	180 -60
Steer E (period 2).....	206	1,753	1,682	
Steer E (period 3).....	197	1,151	1,718	
Steer E (periods 1-3).....				110
Steer C (period 2).....	269	2,184	2,083	-110
Steer C (period 3).....	259	1,539	2,154	
Experiment 209—				
Steer F (period 1).....	301	4,502	2,442	348 -88
Steer F (period 2).....	293	2,756	1,834	
Steer F (period 3).....	283	1,648	2,029	
Steer F (periods 1-3).....				144
MIXED HAY AND MAIZE MEAL:				
Experiment 211—				
Steer G (period 2).....	358	2,332	3,158	572
Steer G (period 3).....	398	7,027	5,840	
MIXED HAY AND HOMINY CHOP:				
Experiment 211—				
Steer D (period 2).....	432	3,511	3,533	86
Steer D (period 3).....	470	7,859	3,905	

^a Basal ration of coarse fodder only.

A simple inspection of Table VII suffices to show that the increment of heat production in standing can not be due to any large extent to the muscular work of supporting the body, since, in the light of Zuntz and Hagemann's (52) experiments on the horse, it must be assumed that this would be at least approximately proportional to the weight of the animal, while, in fact, in a large majority of cases the difference between the periods is very much greater than the corresponding difference in live weight. Even on the extreme assumption that in the periods on minimum rations the heat increment in standing was due exclusively to the increased muscular effort, the differences in live weight do not even remotely account for the greater increments in the other periods.

RELATION TO AMOUNT OF FEED

In spite of the considerable variations in the individual results and of some negative values, it appears clear, both from Table VII and from figure 1, especially if the comparisons be made between the smallest and the greatest rations, that the effect of the feed in increasing the metabolism tended to be distinctly greater during standing than during lying, and that, on the whole, the differences tended to be greater with concentrates or with mixed rations than with coarse feeds. In other words, the difference between the metabolism of the animal when standing and when lying was relatively greater on the heavier than on the lighter rations.

This difference can hardly be ascribed to a greater direct stimulus of cell metabolism by the products of digestion. One explanation for it might be sought in the fact that the feed was consumed by the animal while standing. Experiments by Paechtner (39) and by Dahm (17) on cattle and by Ustjanzew (46) on sheep, in which the respiratory exchange was determined in short periods, showed that the mastication of 1 kg. of hay increased the metabolism of the animal by approximately 60 Calories. In our experiments this would be equivalent to the production during perhaps half an hour after feeding—i. e., at 6 a. m. and 6 p. m.—of from 12 to as much as 200 Calories of heat, or twice this amount in 24 hours, which amounts would be added to the standing metabolism. On the other hand, however, according to the same experimenters, the rumination of the feed would increase the heat production by, roughly, two-thirds as much, and this would constitute to a considerable extent an addition to the metabolism of the animal when lying, thus partially but not wholly compensating for the addition to the metabolism when standing consequent on mastication.

It would appear, then, that the mastication of the heavier rations would tend to increase the ratio of heat production of the animal when standing to that when lying. The heat *elimination*, however, in our experiments showed no distinct evidence of such an increase. The rate of heat emission per minute while the feed was being eaten showed infrequently a slight rise, which was seldom sharp and which was far less than would correspond to the presumable increase in the gaseous exchange. In many instances no effect upon the heat elimination was observed, but rather frequently there was a distinct *fall*. Sometimes, although not in the majority of cases, a rise was observed after the animal had finished eating. The animal was watered after the 6 a. m. feeding. Sometimes no perceptible change in the rate of heat emission resulted, but not infrequently a fall was observed, which was occasionally considerable. It can hardly be doubted that there must have been an increased production of heat during mastication, but apparently this heat was not given off promptly. Part of it at least, it may be conjectured, was applied to warm

the ingesta, especially the water, being eliminated only gradually during the succeeding 12 hours and in part during the periods of lying as well as of standing. It does not seem probable, therefore, that the heat produced in the mastication of the feed was an important factor in causing the differences between the heat elimination of the animals when standing or lying which were observed in these experiments.

Another plausible suggestion seems to be a tendency of the animals to greater restlessness and muscular activity in the standing position when consuming the heavier rations. We are not able to submit direct records to prove this, but indirect evidence is afforded by the fact that the animals as a rule (31 cases out of 40) changed from the lying to the standing position, and vice versa, more frequently on the heavier rations. No such distinct effect was noticeable on the percentage of time spent standing, it being greater in 22 cases and less in 19 on the heavier as compared with the lighter rations and showing a considerable degree of constancy in the individual animal.

INDIVIDUAL DIFFERENCES

In those cases where comparisons between different animals are possible the average results, especially those obtained by comparing the maximum and minimum rations, seem to indicate the existence of distinct individual differences between different animals in this respect.

The most noticeable case of this sort is that of animals A and B, in experiments 190, 200, and 207, steer A being a typical beef animal, while B, although of mixed blood (scrub), was quite distinctly of the dairy type and of a more nervous temperament. In five cases out of six the heat increment due to standing was greater with steer B than with steer A, the average of all the results being 39 per cent higher for the former, as the following summary shows:

Heat increments in Calories per kilogram of dry matter due to standing

Feed.	Steer A.	Steer B.
Timothy hay.....	{ -88 442 364	{ 148 346 628
Timothy hay and wheat bran.....	168	200
Timothy hay and grain mixture No. 1.....	{ 600 610	{ 642 828
Average.....	335	465

A similar instance is afforded in experiments 208 and 209 by the animals C, E, and F. Steer C had received almost from birth as heavy feeding as practicable, while E and F had received the same feeds in quantities sufficient to insure normal growth but not to cause any material fattening. The heat increments per kilogram of dry matter of feed were as follows:

Heat increments in Calories per kilogram of dry matter due to standing

Feed.	Steer C.	Steer E.	Steer F.
Alfalfa hay.....	118	230	304
Alfalfa hay and grain mixture No. 2.....	-110	110	144
Average.....	4	170	224

INFLUENCE OF BULK OF RATION

It seems worth while to call attention also to three cases which suggest that the bulk of the ration may be a factor in determining the difference between the metabolism of the animals when standing and lying. In period 3 of experiments 208 and 209 steers C, E, and F received a light ration, two-thirds of which consisted of grain—i. e., a ration of small bulk—and on this light ration they showed a distinctly greater increment of metabolism during standing than upon one considerably heavier. It seems at least a plausible suggestion that the deficient bulk may have caused a greater degree of restlessness in period 3 and consequently an increased metabolism.

CORRECTION TO UNIFORM STANDING

Since standing or lying exerts such a marked influence on the heat production of animals, it is evident that a correction for this influence must be made before the results of the heat determinations can be regarded as comparable, since, notwithstanding the uniformity of external conditions striven after, the proportion of time spent standing or lying, respectively, varied more or less. As already pointed out this does not seem to have been related to the quantity of feed consumed, the difference having been practically as often in one direction as in the other. The stimulating effect, if such there were, seems to have expressed itself in more frequent changes of posture and a greater intensity of metabolism while standing rather than in more prolonged standing. The percentage of time spent standing appears to be largely a matter of individuality, whatever that convenient term may really signify. If we compare the results in this respect in the several periods, irrespective of the amount and kind of feed, it appears that, with a few exceptions, they show, on the whole, a rather marked degree of uniformity in the individual animal. This is especially true if experiment 190 be excepted, in which the animals were only about 12 months old. The data are contained in Table VIII, the averages in each case being computed, excepting the bracketed numbers.

TABLE VIII.—Percentage of time spent standing

Animal and experiment No.	Period No.	Percentage of time spent standing.	Animal and experiment No.	Period No.	Percentage of time spent standing.
Steer I:			Steer C:		
174.....	{ A	57	208.....	{ 2	[60]
	{ B	68		{ 3	42
	{ C	57		{ 4	47
	{ D	60		{ 5	41
	{ 1	61		{ 6	42
179.....	{ 2	63	Average.....		43
	{ 3	56			
	{ 4	[76]	Steer D:		
186.....	{ 1a	[87]	208.....	{ 1	32
	{ 2a	68		{ 2	30
	{ 3a	62		{ 1	[53]
Average.....		65	210.....	{ 2	38
				{ 3	36
186.....	{ 1b	100		{ 1	30
	{ 2b	81		{ 2	40
	{ 3b	73	211.....	{ 3	24
Average.....		85		{ 4	36
				{ 5	40
Steer A:			Average.....		34
190.....	{ 1	79	Steer E:		
	{ 2	79	208.....	{ 1	30
	{ 3	75		{ 2	27
	{ 4	81		{ 3	39
Average.....		79		{ 4	40
				{ 5	46
200.....	{ 1	52		{ 6	[56]
	{ 2	58	Average.....		36
	{ 3	57	Steer F:		
	{ 4	51	209.....	{ 1	27
207.....	{ 1	50		{ 2	33
	{ 2	64		{ 3	32
	{ 3	46		{ 4	34
	{ 4	49		{ 5	33
Average.....		53		{ 6	46
			Average.....		34
Steer B:			Steer G:		
190.....	{ 1	65	211.....	{ 1	40
	{ 2	46		{ 2	42
	{ 3	58		{ 3	[28]
	{ 4	28		{ 4	35
	{ 1	47		{ 5	30
200.....	{ 2	45	Average.....		37
	{ 3	57	Steer H:		
	{ 4	33	212.....	{ 1	42
	{ 1	48		{ 2	40
207.....	{ 2	46		{ 3	[29]
	{ 3	43		{ 4	38
	{ 4	39		{ 5	34
Average.....		46		{ 6	37
			Average.....		38

In view of this general uniformity, only a comparatively small correction would be necessary in most instances to make the results on an individual animal comparable as regards standing and lying. When, however, it is desired to compare the results obtained with different individuals so as to get a general average, it is clear that the animal which tends to stand most is at a disadvantage and will show a lower net energy value for the same ration not because his feed is any poorer but because the animal is a less efficient converter and that the greater the stimulus to metabolism exerted by standing the greater will this difference become. It is necessary, therefore, to correct the results upon heat production as well as possible to a uniform proportion of standing and lying, so as to render the results applicable to an (assumed) average animal. According to Table VIII the average percentage of time spent standing was 43. In correcting the results, however, we have used 50 per cent as the standard for convenience in calculation—that is, we have taken as the corrected heat production the average of that standing and lying, computed as shown on page 454 for the entire 48 hours.¹

OTHER FORMS OF MUSCULAR ACTIVITY

According to our interpretation of our results, the material increase in the heat production of an animal when standing as compared with that when lying is simply an instance of the well-known influence of muscular exertion upon metabolism. Recent investigators, notably Schlossmann and Murschhauser (42, 43) and Benedict and Talbot (14, 15) in experiments upon infants, and Benedict and Homans (12, 13) in similar trials with dogs, have emphasized the disturbing influence of this factor upon comparisons of different periods. Benedict and his associates, in particular, have devised ingenious methods for determining the degree of muscular activity of a subject and have insisted that only periods of minimum activity can be safely compared.

We have not yet had the courage to attempt to apply to an animal weighing 1,000 or 1,200 pounds methods like those which have been used so successfully for infants and small dogs, either for the indication of minor movements or for the determination of the pulse rate. It seems likely that the latter, in particular, might be of considerable aid in the interpretation of the results if it should prove possible to devise a form of apparatus which would not be injured by the movements of a heavy animal.

¹ This method of correcting the results assumes that the relative intensity of the metabolism of the animal when standing or lying is not affected by the proportion of time spent standing. It might be imagined, however, that in a comparatively long period of standing the original stimulus to incidental muscular movements might gradually fade out, so that the average difference in the rate of metabolism in the two positions would be less for long than for short periods. In this case our method of correcting the results would be more or less erroneous. This possibility can be tested to a certain extent by comparing with each other the two single days of each period. Out of the 64 possible comparisons, that one of the two days in which the lesser percentage of time was spent standing showed a greater increment of standing over lying in 26 cases and a less increment in 37 cases. On the average of the 64 days of maximum standing the percentage of time spent standing was 51.9 and on the 64 days of minimum standing 43.5, while the corresponding average percentage increases in metabolism during standing were, respectively, 41.98 and 41.67. It does not appear, therefore, that within the range of these experiments the ratio of the metabolism when standing to that when lying was materially affected by the proportion of time spent standing.

In considering, however, the weight to be attached to the influence of variations in the muscular activity of the animal, and the degree of refinement necessary in experimental methods, it is important not to forget the main purpose of the experiments. This purpose was, as already explained, substantially an economic one—viz, to determine how much of the energy supplied in metabolizable form by the feed is, under ordinary conditions, dissipated through the heat production caused directly or indirectly by the ingestion of the feed and what proportion of it remains available for the physiological uses of the body. From this point of view it is immaterial whether the increased heat production is caused by "work of digestion" in the narrower sense, by the stimulating effect of the resorbed products of digestion upon the cell metabolism shown by the investigations of Lusk (31, 32, 33, 34, 35, 36, 49), or indirectly by giving rise to increased activity of the voluntary muscles. While it is of interest and value to learn as much as possible of the relative importance of these factors, nevertheless they are "all in the day's work," and from the economic viewpoint their aggregate constitutes the increased energy expenditure consequent upon feed consumption. Even if it were practicable to base comparisons upon periods of minimum activity the results, however interesting physiologically, would include only a part of the effects which the feed actually exerts upon the metabolism. If the feed causes greater restlessness in the animal while standing or causes it to get up and to lie down more frequently, this gives rise, under the conditions of practice, to just as real losses of energy as does the increase of the general cell metabolism when in the lying position and from the economic point of view must be taken into account. What is needed is a comparison of periods of *average* rather than of minimum muscular activity and the correction to 12 hours of standing aims to reduce conditions to such an average (assumed) as regards this very important factor.

Of course, however, the possibility of variations in other forms of muscular activity, arising from differences in external conditions other than the feed, has to be reckoned with. Naturally the endeavor has been to make those conditions as nearly uniform as possible. The feeding was identical from day to day during the three weeks of each period and was given at the same hours. The surroundings during the days spent outside the calorimeter were uniform, and the animals were handled by the same attendants.

During the days in the calorimeter even greater uniformity of conditions existed. The temperature varied only a few hundredths of a degree, the triple walls of the apparatus practically shut off all external sounds except the slight monotonous click of the meter pump, while in the comparatively dim interior the change outside from daylight to artificial light could not have been very noticeable. Visitors were not admitted during the runs. As already stated, all the animals were docile

and accustomed to being handled, to the wearing of the apparatus for the collection of excreta, and to the presence of the observers.

Some idea as to the extent to which these precautions were successful may be formed from a comparison of the quantities of heat produced after correction to 12 hours standing on the two successive days of each 48-hour calorimeter run. The first half of Table IX shows the corrected heat production on the first and second days of each run and likewise the mean, computed in the manner illustrated on page 454 for the entire 48 hours.^a

TABLE IX.—Heat production per day and per head corrected to 12 hours standing

Feeding stuff and experi- ment No.	Animal No.	Period No.	Corrected heat produc- tion.			Analysis of heat production.			
			First day.	Second day.	48-hour mean.	Stand- ing 12 hours.	Rising and lying down.	CH ₄ fer- menta- tion.	Re- main- der.
Timothy hay:									
174.....	{	I A	<i>Cals.</i> 8,788	<i>Cals.</i> 9,316	<i>Cals.</i> 9,049	<i>Cals.</i> 1,112	<i>Cals.</i> 17	<i>Cals.</i> 448	<i>Cals.</i> 7,472
		I B	9,899	9,565	9,769	1,450	18	570	7,731
		I C	10,309	10,723	10,562	1,440	17	626	8,479
		I D	11,013	11,130	11,149	1,437	27	864	8,821
190.....	{	A 3	5,709	5,532	5,636	1,091	12	282	4,251
		A 4	7,535	6,545	6,709	1,023	15	481	5,190
		B 3	4,985	4,904	5,081	875	12	276	3,918
		B 4	6,095	5,886	5,852	937	12	361	4,542
200.....	{	A 3	7,186	7,275	7,245	1,001	25	<i>b</i> 378	5,841
		A 4	8,057	8,205	8,186	1,379	40	<i>b</i> 606	6,161
		B 3	6,773	6,707	6,778	1,093	24	<i>b</i> 367	5,294
		B 4	7,750	7,783	7,837	1,315	33	<i>b</i> 540	5,949
207.....	{	A 3	7,713	7,812	7,791	1,107	40	498	6,146
		A 4	9,267	9,649	9,523	1,438	59	794	7,232
		B 3	7,996	8,070	8,064	1,190	43	481	6,350
		B 4	9,621	9,637	9,812	1,758	51	747	7,256
Red clover hay:									
179.....	{	I 1	10,939	10,910	10,926	2,354	43	626	7,903
		I 2	9,327	9,944	9,621	1,812	28	464	7,317
186.....	{	Ia	9,844	9,586	9,627	1,604	20	413	7,590
		I 3a	9,835	10,618	10,176	1,958	51	464	7,703
		I 2a	10,335	10,945	10,574	2,183	36	555	7,800
		I 3b	10,178	10,197	10,206	1,492	48	464	8,202
	{	I 2b	10,274	10,976	10,501	1,688	38	555	8,220
Mixed hay:									
211.....	{	D 1	11,775	12,995	12,359	1,679	79	805	9,796
		D 4	9,481	9,680	9,625	1,498	76	527	7,524
		D 5	8,291	8,259	8,258	1,497	57	282	6,422
211.....	{	G 1	12,211	11,971	12,098	1,802	80	830	9,386
		G 4	9,843	9,242	9,568	1,958	75	457	7,078
		G 5	7,811	7,178	7,477	1,382	62	261	5,772

^a The 48-hour means differ from the means of the 24-hour periods for two reasons: First, the percentage increase of the metabolism when standing over that when lying varied in the two days, as did also the percentage of the total heat carried off as latent heat of water vapor. On account especially of the latter difference, the mean of the two days taken singly differs from that computed from the average heat production per minute standing and lying for the whole 48 hours. Second, in experiments 190, 200, and 207 the corrected results for the 48 hours are computed from selected portions of the runs in the manner described in an earlier publication (10, p. 43), and therefore differ from the mean of the results for the single days.

^b Methane computed from digested carbohydrates.

TABLE IX.—Heat production per day and per head corrected to 12 hours standing—Con.

Feeding stuff and experiment No.	Animal No.	Period No.	Corrected heat production.			Analysis of heat production.			
			First day.	Second day.	48-hour mean.	Standing 12 hours.	Rising and lying down.	CH ₄ fermentation.	Remainder.
Alfalfa hay:			Cals.	Cals.	Cals.	Cals.	Cals.	Cals.	Cals.
	D	1	5,385	5,442	5,411	1,000	39	256	4,116
	D	2	4,243	4,290	4,266	612	45	161	3,448
	E	4	7,931	7,823	7,879	1,014	58	457	6,350
208.....	E	5	5,759	5,764	5,764	796	45	302	4,621
	E	6	4,529	4,590	4,566	732	24	180	3,630
	C	4	8,905	9,100	9,052	1,297	48	470	7,237
	C	5	7,340	7,391	7,357	1,292	38	380	5,647
	C	6	6,136	6,122	6,124	1,156	34	271	4,663
209.....	F	4	11,228	11,432	11,474	1,400	86	697	9,291
	F	5	.....	8,031	8,007	948	43	420	6,587
	F	6	6,819	6,794	6,781	830	54	285	5,612
212.....	H	1	11,424	11,186	11,272	1,522	62	837	8,851
	H	3	10,189	10,616	10,388	1,549	63	685	8,091
	H	5	7,836	7,582	7,754	1,196	45	415	6,098
Alfalfa meal:									
212.....	H	2	11,025	11,505	11,252	1,570	53	760	8,869
	H	4	9,889	10,270	10,066	1,425	46	638	7,957
	H	6	7,027	7,132	7,069	1,146	42	419	5,462
Maize stover:									
210.....	D	1	9,550	9,203	9,363	1,428	31	495	7,409
	D	2	8,605	8,404	8,495	1,199	44	405	6,847
	D	3	7,527	7,429	7,476	1,250	59	308	5,859
Maize meal added to clover hay:									
179.....	I	2	9,327	9,944	9,621	1,812	28	464	7,317
	I	3	10,483	9,876	10,198	2,284	45	630	7,239
	I	4	12,723	13,354	12,947	3,124	21	1,110	8,689
Wheat bran added to timothy hay:									
190.....	A	3	5,709	5,532	5,636	1,091	12	282	4,251
	A	1	7,819	7,328	7,739	1,486	12	503	5,738
	A	2	.....	8,400	8,385	1,307	13	643	6,422
	B	3	4,985	4,904	5,081	875	12	276	3,918
	B	1	6,493	6,299	6,363	865	6	400	5,092
	B	2	6,814	7,117	7,409	1,057	11	537	5,804
Grain mixture No. 1 added to timothy hay:									
200.....	A	3	7,186	7,275	7,245	1,001	25	378	5,841
	A	1	8,955	9,236	9,274	1,322	32	679	7,241
	A	2	12,140	12,667	12,514	2,226	48	1,043	9,197
	B	3	6,773	6,707	6,778	1,093	24	367	5,294
	B	1	8,916	8,952	9,016	1,427	17	556	7,016
	B	2	9,810	9,710	9,909	1,771	25	684	7,429
	A	3	7,713	7,812	7,791	1,107	40	498	6,146
	A	1	9,786	10,181	10,164	1,294	58	841	7,971
	A	2	13,534	12,738	13,375	2,518	73	1,222	9,562
207.....	B	3	7,996	8,070	8,064	1,190	43	481	6,350
	B	1	9,434	9,568	9,600	1,558	24	733	7,285
	B	2	11,658	11,640	11,720	2,285	45	954	8,436

a Basal ration of coarse fodder only.

TABLE IX.—Heat production per day and per head corrected to 12 hours standing—Con.

Feeding stuff and experiment No.	Animal No.	Period No.	Corrected heat production.			Analysis of heat production.			
			First day.	Second day.	48-hour mean.	Standing 12 hours.	Rising and lying down.	CH ₄ fermentation.	Remainder.
Alfalfa hay and grain mixture No. 2:			Cals.	Cals.	Cals.	Cals.	Cals.	Cals.	Cals.
	E	1	7,434	7,532	7,483	916	56	464	6,047
	E	2	5,940	5,911	5,924	788	53	393	4,780
208.....	E	3	5,032	5,138	5,084	824	35	165	4,060
	C	2	6,802	6,927	6,858	1,011	31	388	5,428
	C	3	6,096	6,149	6,123	1,043	34	284	4,762
209.....	F	1	9,679	10,099	9,888	1,132	89	562	8,105
	F	2	7,645	7,809	7,115	844	73	382	5,816
	F	3	6,791	6,659	6,734	948	68	253	5,465
Mixed hay and maize meal:									
211.....	G	2	8,678	8,362	8,470	1,505	74	470	6,421
	G	3	14,510	14,467	14,561	2,852	68	1,126	10,515
Mixed hay and hominy chop:									
211.....	D	2	9,782	10,126	9,947	1,695	71	643	7,538
	D	3	14,877	15,040	14,936	1,850	102	1,216	11,768

As already stated, we estimate the experimental error in the determination of the heat emitted by the animal to be approximately 1 per cent. In the 73 cases in which a comparison of the two days can be made, 40 show a deviation from the mean of the two 24-hour results of less than 1.1 per cent—i. e., the results for the two days practically agree within the limits of experimental error. Of the 53 experiments made since 1905—i. e., experiments 200 to 212—which, in our judgment, are, on the whole, more accurate than the earlier ones, 36 fall within this limit or error. On the other hand, however, deviations as great as 2 per cent are not uncommon, while occasionally they rise to as much as 5 per cent or even 7 per cent. The mean of the percentage deviations is for the entire series 1.45 per cent and for experiments 200 to 212, inclusive, 1.13 per cent. Moreover, the deviations of the single days from the mean are, on the whole, fully as great after reduction to 12 hours standing as before. It is clear, therefore, that despite the apparent uniformity of experimental conditions the metabolism of the animals was affected by influences other than the feed or the proportion of time spent standing.

Mr. H. H. Mitchell, of the Illinois Experiment Station, has had the kindness to submit these data to mathematical study and finds that they present clear evidence of the existence of individual differences between the animals as regards the agreement between the two days. He writes as follows:

It seems very evident to me both from inspection of the data and from statistical calculations that the percentage deviation of duplicate determinations of the heat

production of animals is variable, depending undoubtedly upon the particular animal under investigation and possibly, also, upon the nature of the ration. Thus the average percentage deviations for the four animals for which 10 or more observations are recorded, with their probable errors, are:

Animal I.....	2.10±0.23
Animal A.....	^a 2.25±0.35
Animal A.....	^b 1.77±0.18
Animal B.....	0.75±0.13
Animal D.....	1.32±0.28

While, according to these figures, animals I and A can not be differentiated from each other, they are both clearly differentiated from animal B, the differences, with their probable errors, being 1.35 ± 0.26 between animals I and B and 1.02 ± 0.22 between animals A and B. The difference between animals I and D was 0.78 ± 0.36 , the significance of which may be questioned. Using another method of comparison, it may be shown that the odds are 124 to 1 that animals C and H are definitely distinct as regards the percentage deviation under discussion. I should not hesitate to conclude, therefore, that this percentage deviation is affected by the individuality of the experimental animals. Furthermore, there is a slight suggestion, especially in the data of animals A and B, that the nature of the ration may affect the percentage deviation of your determinations.

It is of interest to note in this connection that the results of Kellner's respiration experiments (uncorrected for standing or lying) likewise show variations of much the same order of magnitude between individual (not consecutive) days. When, therefore, comparisons are based upon the average results for 48 hours, it is impossible to assert that these results represent, as they should, periods of average muscular activity, although it would appear that the error thus introduced is usually not large. In Kellner's experiments it is still further reduced by the fact that in most cases the results of four or five single runs are averaged.

ANALYSIS OF HEAT PRODUCTION

In Table VII were shown the increments of heat production per 24 hours in standing animals as compared with those lying. It is evident that of the total corrected heat production recorded in Table IX an amount equal to one-half of the corresponding increment shown by Table VII is to be regarded as the effect of the 12 hours' standing, while the remainder represents the metabolism of the animal per 24 hours lying. On the basis of Zuntz's recent results it is possible to carry this analysis of the heat production a little farther, at least approximately. The expenditure of energy caused by standing obviously includes that required for the muscular effort of rising and lying down. Von der Heide, Klein, and Zuntz (20, p. 823) estimate this on the basis of experiments by Klein at 9.7 Calories per 550 kg. of live weight for once rising and lying down again. The same investigators (20, p. 795) compute from Markoff's experiments (37, 38) that the methane fermentation in cattle gives rise to the evolution of 4.374 Calories of heat per cubic centimeter of methane, equivalent to 6.07 Calories per gram. While both the foregoing figures are confessedly but approximations, nevertheless they permit a partial analysis of the heat production with

^a Including questionable observation.

^b Not including questionable observation.

the results shown in the second part of Table IX. The "remainder" shown in the last column includes the so-called basal or fasting metabolism, together with the effect of the feed in increasing the muscular activity of the organs of digestion and of the voluntary muscles in the lying position, as well as in directly stimulating the cell metabolism. No sufficient data are available for further analysis of this "remainder."

PROPORTION OF FEED ENERGY EXPENDED IN HEAT PRODUCTION

METHOD OF DETERMINATION

The total metabolism of an animal upon any particular ration, as illustrated by the figures of Table IX, is made up of numerous factors, and a single experiment affords no means of determining the proportion due to the consumption of feed. This can be determined only by a comparison of two periods, otherwise identical, in which different quantities of the same feed are consumed, the additional heat production on the heavier ration constituting the measure of the additional energy expended. With carnivora and with man the comparison may be made with the fasting state—i. e., the amount of feed in one of the periods may be zero. With cattle this is impracticable for obvious reasons, and it is necessary to make the comparison with a period upon a so-called basal ration. Kühn and Kellner added the feeding stuffs to be tested to a mixed basal ration that was more than sufficient for maintenance. In our earlier tests, up to experiment 207, inclusive, the same general plan was followed, except that the basal ration consisted of coarse feeds only and was in most cases below the maintenance requirement. In the later experiments the method was modified by feeding different quantities of the same feed or mixture of feeds both above and below the maintenance requirement. The method of comparison for a ration consisting of a single feeding stuff is very simple. Thus, in experiment 207 the following results were obtained on timothy hay with steer A in periods 3 and 4. The same method of comparison may obviously be applied also to different amounts of a mixed ration of grain and hay.

Computation of energy expenditure by steer A per kilogram of timothy hay eaten

Item.	Quantity of dry matter eaten.	Total heat production.	Distribution of heat production.			
			Standing.	Rising and lying down.	Fermentation.	Remainder.
Period 4.....	Gm. 4,892	Calories. 9,523	Calories. 1,438	Calories. 59	Calories. 794	Calories. 7,232
Period 3.....	2,974	7,791	1,107	40	498	6,146
Difference.....	1,918	1,732	331	19	296	1,086
Difference per kilogram of dry matter.....	.....	903	173	9	154	567

The comparison of these two periods shows that each additional kilogram of dry matter consumed increased the total heat production by 903 Calories, 173 of which represent energy expended in standing, 9 that expended in rising and lying down, and 154 the additional heat due to the methane fermentation, while the remainder, 567 Calories, represents the increased mechanical work of digestion plus any stimulus which the digested nutrients exerted upon the cell metabolism. Obviously the calculation by difference eliminates the basal metabolism.

For concentrated feeds, which can not be fed alone, two methods have been used, as already noted. In the earlier experiments, the concentrate was added to the basal ration of coarse fodder. Thus, in period 2 of the experiment just used as an illustration a mixture of grains (grain mixture No. 2) was added to the basal ration of period 3 with the following results:

Computation of energy expenditure by steer A per kilogram of grain eaten

Item.	Quantity of dry matter eaten.		Total heat production.	Distribution of heat production.			
	Hay.	Grain.		Standing.	Rising and lying down.	Fermentation.	Remainder.
Period 2.....	Gm. 2,949	Gm. 4,759	Calories. 13,375	Calories. 2,518	Calories. 73	Calories. 1,222	Calories. 9,562
Period 3.....	2,974	.....	7,791	1,107	40	498	6,146
Difference.....	-25	4,759	5,584	1,411	33	724	3,416
Difference per kilogram of dry matter.....	.....	.....	1,179	298	7	153	721

Each kilogram of dry matter of the grain increased the heat production by 1,179 Calories, which can be subdivided as before in the proportions shown.¹ The greater expenditure of energy per kilogram in the case of grain as compared with hay is seen to be due in part to a greater increase of the metabolism of the animal when standing and in part either to increased mechanical work in digestion or more likely to a greater stimulus of the cell metabolism.

In later experiments (Nos. 208 to 212, inclusive), in place of adding grain to a ration of coarse fodder, the animals received varying quantities of a uniform mixture of coarse fodder and grain, the energy expenditure caused by the total ration being determined substantially in the manner already illustrated. The portion of the increase due to the grain alone was computed by subtracting from the total increase that due to the hay as determined in two or more separate periods on exclusive hay rations.² The method may be illustrated by the results obtained with steer E in periods 1 and 3 of experiment 208.

¹ Logically the results of the comparison should be corrected for the slight difference (25 gm.) in the amount of dry matter of hay consumed. As a matter of fact, however, this correction is insignificant in all the experiments, amounting in the present instance to about 1 Calorie.

² When more than two periods of hay feeding were used the increased heat production per kilogram of hay was computed by comparing the periods on the heaviest and the lightest rations.

Computation of energy expenditure of steer E per kilogram of grain eaten

Item.	Quantity of dry matter eaten.		Total heat production.	Distribution of heat production.			
	Hay.	Grain.		Standing.	Rising and lying down.	Fermentation.	Remainder.
Period 1.....	Gm. 1,086	Gm. 2,122	Calories. 7,483	Calories. 916	Calories. 56	Calories. 464	Calories. 6,047
Period 3.....	387	764	5,084	824	35	165	4,060
Difference.....	699	1,358	2,399	92	21	299	1,987
Difference due to 699 gm. of hay ^a.....	.....	.....	840	71	9	70	690
Difference due to 1,358 gm. of grain.....	.....	.....	1,559	21	12	229	1,297
Difference per kilogram of grain.....	.....	.....	1,148	15	9	169	955

^a Computed from a comparison of periods 4 and 6.

DIFFERENCES IN LIVE WEIGHT

As the figures of Table VII show, the live weight of the animals varied more or less in the different periods. To what extent do these variations affect the conclusions drawn from comparisons like those just illustrated?

Two effects other than those due directly to the amount of feed might be anticipated from an increase in the live weight: First, an increase in the basal metabolism due to a greater mass of tissue, and, second, an increase in the muscular work of supporting the body in the standing position. As regards the first of these, it is to be remarked that the experimental periods were short (three or, in a few cases, four weeks only) while the changes in the amount and kind of feed consumed were considerable. It seems altogether probable that the larger part of the variation in weight must be ascribed to "fill"—i. e., to variations in the contents of the digestive tract rather than to any considerable change in the make-up of the body proper—and that the actual basal metabolism was not greatly affected. As regards the effect upon the muscular work of standing, it has been already pointed out that this appears to be a relatively small factor in the total increase of heat elimination in standing. In view of these considerations, it is to be anticipated that a correction of the heat production in proportion to either the weight or the surface of the animals would materially exaggerate the effect upon the metabolism, and, on the whole, we have regarded it as safer to disregard the variations in live weight rather than to attempt a more or less conjectural correction.

HEAT INCREMENTS PER KILOGRAM OF DRY MATTER

The results of the comparisons between periods made by the methods just illustrated are contained in Table X. In those cases in which more than two periods upon the same ration can be compared, the total heat increments per kilogram of dry matter are recorded for each successive

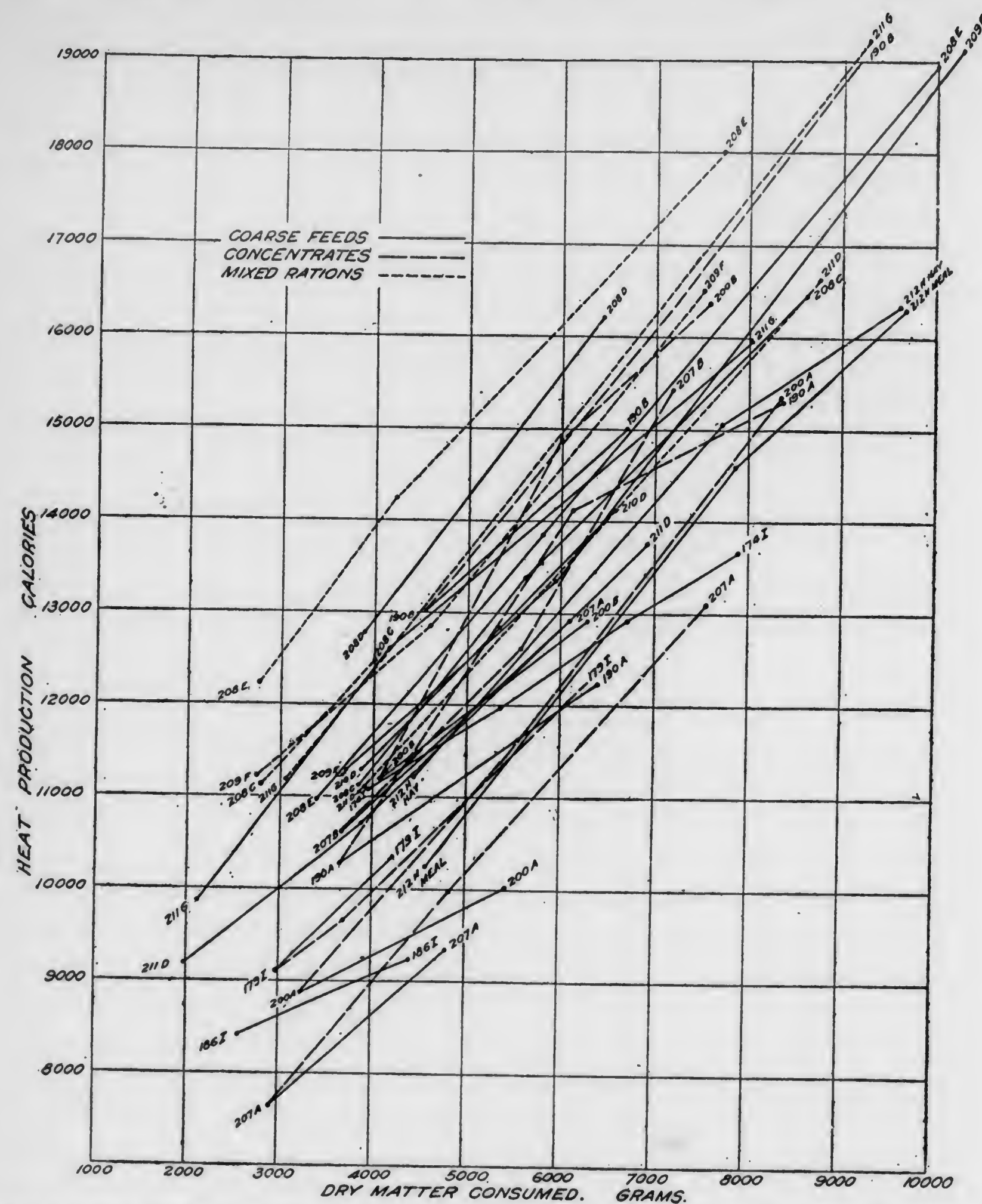


TABLE X.—Increments of heat production per kilogram of dry matter—Continued

Feeding stuff and experiment No.	Animal No.	Successive amounts of feed.			Comparison of greatest and least amounts of feed.	Analysis of heat increments.			
						Standing 12 hours.	Rising and lying down.	CH ₄ fermentation.	Remainder.
Alfalfa meal: 212.....	H	Cals. 1,330	Cals. 939	Cals.	Cals. 1,190	Cals. 121	Cals. 3	Cals. 97	Cals. 969
Average of alfalfa hay and meal.....		1,184	1,028	.....	1,169	161	5	101	902
Maize stover: 210.....	D	1,034	1,101	.....	1,065	101	-16	105	875
Alfalfa hay and grain mixture No. 2: 208.....		1,395	1,072	.....	1,166	45	10	145	966
209.....	E C F	886	1,244	.....	1,139	-50	-5	161	1,033
Average.....		1,146	1,160	.....	1,105	64	7	108	926
Alfalfa hay and grain mixture No. 2 (periods 1 and 2): 208.....	E C F	.....	.....	.....	1,139	20	4	138	977
209.....		.....	.....	.....	1,072	88	2	111	871
Average.....	E C F	.....	.....	.....	1,248	169	9	103	971
Mixed hay and maize meal: 211.....		.....	.....	.....	1,160	127	5	107	921
Mixed hay and hominy chop: 211.....	G	.....	.....	.....	1,297	287	-1	140	871
Maize meal added to clover hay: 179.....		765	1,004	.....	952	375	-1	185	393
Maize meal (computed): 211.....	G	.....	.....	.....	1,434	386	-4	146	906
Hominy chop (computed): 211.....		.....	.....	.....	1,365	30	9	146	1,180
Wheat bran added to timothy hay: 190.....	A B	1,561	525	.....	1,066	84	0	140	842
Average.....		1,246	1,343	.....	1,288	101	-1	144	1,044
		1,404	934	.....	1,177	93	-1	142	943

TABLE X.—Increments of heat production per kilogram of dry matter—Continued

Feeding stuff and experiment No.	Animal No.	Successive amounts of feed.			Comparison of greatest and least amounts of feed.	Analysis of heat increments.			
						Standing 12 hours.	Rising and lying down.	CH ₄ fermentation.	Remainder.
Grain mixture No. 1 added to timothy hay: 200.....	A B A B	Cals. 1,157	Cals. 1,348	Cals.	Cals. 1,267	Cals. 294	Cals. 6	Cals. 160	Cals. 807
207.....		1,933	935	.....	1,482	321	0	150	1,011
Average.....	E C F	1,213	1,156	.....	1,179	298	7	153	721
Grain mixture No. 2 (computed): 208.....		1,129	1,640	.....	1,378	413	1	178	786
209.....	E C F	1,494	1,004	.....	1,148	15	9	169	955
Average.....		759	1,277	.....	1,152	-99	-9	202	1,058
Grain mixture No. 2 (computed from periods 1 and 2): 208.....	E F	1,127	1,141	.....	1,125	-19	2	160	982
209.....		.....	.....	.....	1,004	80	-3	116	811
Average.....	E F	.....	.....	.....	1,277	175	9	103	990
		.....	.....	.....	1,141	128	3	110	900

CRITICAL TEMPERATURE

In order that comparisons like the foregoing shall be valid, the experiments must, of course, be made above the so-called "critical temperature" for the animal experimented with and for the minimum quantity of feed consumed, since below this temperature part of the heat produced is utilized to maintain the body temperature and thus to reduce the amount of heat liberated by the katabolism of body substance (2, p. 347-359, 407-410). Our experiments have been made at about 17° to 18° C., and we have not attempted to determine the critical temperature for cattle, but the fact clearly shown in figure 2 that the heat production per kilogram of feed consumed showed no tendency to increase as the rations were made heavier leads us to believe that even on the lightest rations the temperature was safely above the point at which the so-called "chemical" regulation of body temperature begins. Kellner's experiments were made at somewhat lower temperatures, mostly between 12° and 15° C., but on heavier rations.

DISCREPANCIES IN RESULTS

It is apparent from both Table X and figure 2 that the single results show a considerable range for the same or similar feeds not only with different animals but also, in some instances, between different periods with the same animal. For example, in experiment 209, on steer F with alfalfa hay an increase of the ration from 2,226 to 3,562 gm. of dry matter caused an increase in the (corrected) heat production at the rate of 963 Calories per kilogram, while a further increase to 6,174 gm. resulted in a relatively greater increase of the heat production—viz, 1,301 Calories per kilogram.

In the instance just cited one might be inclined to interpret the difference as an effect of the greater feed consumption. The next line in Table X, however, shows an even greater difference in the opposite direction, while it is evident from figure 2 that the data as a whole show about as many differences in one direction as the other and, as pointed out in the previous paragraph, fail to give any distinct evidence of a greater relative increase of heat production on heavy as compared with light feed or on supermaintenance as compared with submaintenance rations, the averages tending, if anything, to be a trifle lower on the heavier rations.

Unavoidable differences in the muscular activities of the animal, other than those connected with standing and lying, and in other conditions have also to be considered. As already pointed out, the existence of such differences, in spite of the uniformity of the controllable experimental conditions, is indicated by the occasionally considerable divergence of the heat production upon the two days of the calorimeter runs. It is not improbable, therefore, that they may be responsible, at least in part, for the observed discrepancies, so that it is obvious that the average results must be accepted with some reserve. On the other hand, however, it must be remembered that these are calculations by difference and that in such a calculation the experimental errors tend to accumulate in the final result. Obviously the greater we make the difference in the factor whose effect is to be determined, the less will be the relative error of the final result.¹ We believe, therefore, that the results obtained by a comparison of the extreme rations, as recorded in column 4 of Table X, are decidedly more trustworthy than those computed from the intermediate rations, and, notwithstanding the discrepancies just mentioned, are inclined to regard them as expressing the total effect of the feed in increasing the metabolism, when variations in the time of standing are eliminated, with a sufficient degree of accuracy to warrant general comparisons of the average results. These average results, both as to the total heat increment and its factors, are summarized in Table XI.

¹ Out of 13 cases in which the results appear abnormally high or low, there were 6 in which the difference in dry matter consumed was less than 1 kg., although there were 5 other cases in which, with a similar small difference in the dry matter consumed, apparently normal results were obtained.

TABLE XI.—Average increments of heat production per kilogram of dry matter

Feeding stuff.	Total increment.	Analysis of heat increment.			
		Standing 12 hours.	Rising and lying down.	CH ₄ fermentation.	Remainder.
COARSE FODDERS:	Cals.	Cals.	Cals.	Cals.	Cals.
Timothy hay	782	141	5	132	504
Red clover hay:					
Average	723	344	10	96	273
Experiment 179	992	412	11	123	446
Mixed hay	980	68	4	123	785
Alfalfa hay	1,165	169	5	102	889
Alfalfa meal	1,190	121	3	97	969
Average of alfalfa hay and meal	1,169	161	5	101	902
Maize stover	1,065	101	-16	105	875
MIXED RATIONS:					
Alfalfa hay and grain mixture No. 2					
Average of all	1,139	20	4	138	977
Average of periods 1 and 2 only	1,160	127	5	107	921
Mixed hay and maize meal	1,297	287	-1	140	871
Mixed hay and hominy chop	1,147	36	7	132	972
CONCENTRATES:					
Maize meal added to clover hay	952	375	-1	185	393
Maize meal computed from mixed ration	1,434	386	-4	146	906
Hominy chop computed from mixed ration	1,365	30	9	146	1,180
Wheat bran added to timothy hay	1,177	93	1	142	943
Grain mixture No. 1 added to timothy hay	1,327	331	4	161	831
*Grain mixture No. 2 computed from mixed ration	1,125	-19	2	160	982
The same from periods 1 and 2 only	1,141	128	3	110	900

COMPARISON OF COARSE FEEDS AND CONCENTRATES

The average results recorded in Table XI for the total increase in metabolism resulting from the consumption of 1 kg. of dry matter of the several rations—i. e., for the so-called "work of digestion" in the widest sense—are far from being in accord with common conceptions. Unconsciously misled by an unfortunate terminology, we have been accustomed to think of the more coarse and woody feeds, like hay, straw, stover, etc., as requiring a greater expenditure of energy in their digestion and assimilation than the more concentrated and highly digestible grains, for example. It may be somewhat surprising, therefore, to note the relatively small differences found in this respect between different classes of feeding stuffs, as shown by the averages of Table XI and by figure 2. For example, the expenditure of energy caused by maize meal in experiment 179 was almost as great as that caused by

the clover hay with which it was fed, while in experiment 211 it was apparently distinctly greater than that due to the mixed hay consumed with it. Grain mixture No. 1 decidedly exceeded timothy hay in this respect, and grain mixture No. 2 was nearly equal to alfalfa hay.

As a matter of fact, however, these results are in general harmony with those of other investigators, particularly Kellner. The senior writer (2, p. 492) pointed out some 12 years ago that the total expenditure of energy consequent upon feed consumption, as computed from Kellner's published experiments, is strikingly uniform for the several materials experimented upon with the exception of wheat gluten, the average results computed per kilogram of dry matter being quite of the same order as those here reported, viz:

Average energy expenditure per kilogram of dry matter

	Calories.		Calories.
Meadow hay.....	1,254	Peanut oil.....	^a 1,727
Oat straw.....	1,014	Wheat gluten:	
Wheat straw.....	1,138	Kühn's experiments.....	2,558
Extracted straw.....	1,160	Kellner's experiments.....	2,096
Starch:		Beet molasses.....	988
Kühn's experiments.....	1,508		
Kellner's experiments—			
Moderate rations.....	1,248		
Heavy rations.....	903		

Kellner's later experiments (24, ed. 6, p. 160-168) have not yet been published in full, so that it is not possible to make an exact computation of the energy expenditure. In certain cases, however, the percentages of digestible nutrients are reported. If the corresponding amount of metabolizable energy be computed, using the factors given on page 453, and from this the amount of energy gained by the animal subtracted, the difference will represent approximately the energy spent in digestion, etc. The results of such computations are as follows:

Energy expenditure per kilogram of dry matter, computed from Kellner's experiments

Feeding stuff.	Digestible nutrients.	Computed metabolizable energy.	Gain in energy by animal.	Energy expended in feed consumption.
	Gm.	Calories.	Calories.	Calories.
Cottonseed meal.....	647	2,588	1,869	719
Peanut meal.....	672	2,688	1,798	890
Palm-nut meal.....	624	2,496	1,739	757
Linseed meal.....	690	2,760	1,828	932
Barley straw.....	464	1,624	747	877
Clover hay.....	498	1,743	811	932
"Grass hay".....	528	1,848	803	1,045
Rowen.....	487	1,705	747	958

The approximate results thus computed for the coarse fodders are comparable in a general way with ours upon similar feeds, although

^a One very high result was rejected.

somewhat lower than Kellner's direct results just cited. Those on the oil meals appear relatively lower than ours, although even then they are not much lower than those for the coarse feeds, but it may be questioned whether the estimates of the metabolizable energy of these feeds are not too low.

FACTORS OF INCREASED METABOLISM

Even the very approximate and partial analysis of the total heat production which is attempted in the second part of Tables IX, X, and XI serves to show that the degree of uniformity noted in the preceding paragraph, so far from being surprising, was rather to be expected. The notion of a greater expenditure of energy on coarse feeds is based on the idea that this expenditure is largely for mechanical work. The analysis of the heat production attempted on preceding pages, however, even though only approximate, clearly shows that a considerable portion of the increase in heat production is due to other causes. Roughly, from 9 to 17 per cent of the increase is computed to have had its source in the methane fermentation, while from 3 per cent to as much as 30 or 40 per cent appears to have been due to increased muscular activity while standing. The "remainder" may be regarded as consisting of the mechanical work of digestion plus the stimulus which the feed exerted upon the general metabolism of the animal. How large the latter factor is we have no means of determining, but apparently it is not inconsiderable.

It would seem that the energy expended in peristalsis can not be widely different per kilogram for the different classes of feeding stuffs. On the other hand, the work of mastication and rumination has been shown to be distinctly greater for the coarse feeds. On the basis of Paechtner's (39) and of Dahm's (17) experiments on cattle it may be roughly estimated at 100 Calories per kilogram for hay. Zuntz and Hagemann (52) found the work of masticating oats by the horse to be 28 per cent of that required for hay. On this basis an expenditure by cattle of approximately 28 Calories per kilogram of concentrated feeds, may be estimated. If these amounts are subtracted from those shown in the last column of Table XI, the following approximate figures are obtained per kilogram of dry matter consumed for the work of peristalsis plus the food stimulus to the general metabolism:

COARSE FEEDS		CONCENTRATES	
	Calories.		Calories.
Timothy hay.....	404	Maize meal.....	878
Clover hay (experiment 179)....	346	Hominy chop.....	1,152
Mixed hay.....	685	Wheat bran.....	915
Alfalfa hay.....	802	Grain mixture No. 1.....	803
Maize stover.....	775	Grain mixture No. 2.....	872

Whether the expenditure of energy in peristalsis in cattle is as small as it appears from recent investigations to be in man and in the carnivora it is impossible to say, but one can hardly avoid the impression that the considerable differences shown by the foregoing figures, and

especially the generally higher results for the concentrates, indicate that the direct stimulation of metabolism is a large factor.

It appears, then, that while the mechanical work required for the digestion of concentrates is somewhat less than that necessary in case of coarse fodders, this difference is more than compensated for by other factors, so that on the whole fully as great an increase in the heat production is caused by the consumption of the concentrates. As a class, concentrates are superior to coarse fodders, not because their consumption involves a less expenditure of energy, but because they contain more metabolizable energy, so that more remains available for body use after that expenditure has been met.

DIFFERENCES BETWEEN FEEDING STUFFS

But while our results do not show the existence of as great differences between the two great classes of feeding stuffs in their effects on the energy expenditure of the body as seems to have been at times assumed, they nevertheless reveal distinct differences even between feeding stuffs of the same class. Thus, among the hays (if the results of experiment 179 for clover hay are accepted) a regular increase is found in the total energy expenditure from timothy hay with an average of 782 Calories through mixed hay and clover hay up to alfalfa with an average of 1,169 Calories. Apparently the legumes cause a distinctly greater increase in the metabolism than the Poaceae (Gramineae). In the case of red clover, the difference, according to the meager results obtained, appears to result chiefly from a stimulation of the metabolism due to standing. With alfalfa, on the contrary, the increase in the standing metabolism is not materially greater than in the case of timothy hay, while that due to fermentation is somewhat less. The chief difference between the two seems to lie either in their effect upon the work of peristalsis or in the degree to which they stimulate the general metabolism. One can hardly doubt that the latter is the chief cause and is naturally inclined to associate it with the higher percentage of protein in the legumes. That other causes may also be operative, however, is indicated by the result on maize stover, which is nearly as high as in the case of alfalfa and shows a similar distribution among the several factors.

Among the concentrates there may be noted particularly the marked effect of maize in both the two not very satisfactory experiments in noticeably increasing the standing metabolism. This result is of special interest in view of Zuntz and Hagemann's observations (52, p. 259) on the stimulating effect of maize upon the metabolism of the horse, which were also made on the standing animal, although no increase in the minor muscular activity is reported. Grain mixture No. 1, containing 43 per cent of maize meal, likewise showed a similar effect, although with grain mixture No. 2, containing 60 per cent of maize, it was much less marked, possibly on account of the lower content of protein (12.5 as compared with 17.5 per cent). The increases caused by wheat bran

and by hominy chop, on the other hand, appear to have affected chiefly the metabolism of the animal when lying.

INDIVIDUAL DIFFERENCES

Attention was called on pages 460-461 to the existence of individual differences in the effect of the feed on the ratio of the standing to the lying metabolism. These differences seem in some instances to extend also to other factors of the total heat increment. While the single results are more or less variable, this fact seems to be brought out clearly in the averages. The most striking example is afforded by the animals A and B in experiments 190, 200, and 207, for which the following averages may be computed, showing the heat increments per kilogram of feed to have been distinctly greater with steer B than with steer A. This is, of course, the converse of the conclusion recorded in an earlier publication (10).

Average heat increments of steers A and B per kilogram of dry matter

Feeding stuff.	Animal No.	Total increment.	Distribution.			
			Standing 12 hours.	Rising and lying down.	Methane fermentation.	Remainder.
		Calories.	Calories.	Calories.	Calories.	Calories.
Timothy hay.....	A	717	113	6	139	459
	B	890	183	4	126	577
Timothy hay and wheat bran..	A	1,066	84	0	140	842
	B	1,288	101	-1	144	1,044
Timothy hay and grain mixture No. 1.	A	1,223	296	7	156	764
	B	1,430	367	1	164	898

No such distinct differences were observed between the other animals, which, however, were all of similar type. While steers C, E, and F showed an increased effect upon the standing metabolism in the order named the difference in the metabolism of the animals when lying shows on the average an approximately equivalent decrease, so that no material difference in the total effect resulted.

SUMMARY

Tables X and XI include the results of all of our experiments which have been so far computed as to permit their discussion. In seeking to derive from the recorded results for the increased energy expenditure consequent upon the consumption of certain feeding stuffs general averages which may, with the reservations made on previous pages, afford a basis for estimating the energy values of classes of feeding stuffs and of mixed rations, a certain degree of freedom of choice and the exercise of the judgment of the experimenters seems warranted. Of our results, those on clover hay in experiment 186 appear to us particularly questionable. In one period the animal did not lie down during the entire 48 hours, while in two other periods the time spent in lying was much less than normal. Furthermore, there was a considerable difference

between the observed and the computed heat production in four out of six periods, although it is true that this difference was not relatively greater than in experiment 190. Whether these facts are in any degree responsible for what seem abnormally low results and for the very large proportion of the heat increment apparently due to stimulation of the standing metabolism, it is hard to say, but the results differ so widely from all the others that we feel justified in rejecting them, pending other experiments, particularly since the total increment observed in experiment 179 agrees very well with that computed on page 478 from Kellner's experiments. Experiment 212 fails to show any significant difference between alfalfa hay and alfalfa meal, and the two have been averaged together. In the case of maize meal it is difficult to decide which, if either, of the discordant results is worthy of most credit. The figure of only 393 Calories per kilogram for the increase of the metabolism of the animal when lying, however, seems so low that we are inclined to attach greater weight to the later experiment. For grain mixture No. 2 we have used the results computed from periods 1 and 2 in the belief that the heat production in period 3 was rendered abnormally high by the restlessness of the animals, owing to the small bulk of their ration (compare p. 461), although the difference is scarcely significant.

In the Möckern experiments Kellner's results on heavy rations of starch appear to be abnormal in that the methane production was not increased, while much starch escaped digestion. Kühn's results were obtained on rations of coarse fodder and starch alone with a nutritive ratio of about 1:20, or even wider—i. e., under conditions seldom or never realized in practice. Kellner's average for medium rations, therefore, would appear to correspond most nearly to normal conditions. The results on peanut oil were irregular in several respects, but the rejection of the very high result with ox D seems justified. Of the computed results of Kellner's experiments, as given on page 478, those for the oil meals seem unquestionably too low and have been rejected.

On the foregoing assumptions we have formulated the following averages for the total energy expenditure resulting from the consumption of 1 kg. of the dry matter of the feeds named. It may not be superfluous to call attention again to the fact that these figures are simply general averages, derived in some instances from quite discordant single results, and that, as both our own and the Möckern experiments show, they are subject to very considerable variations in individual cases.

Average energy expenditure per kilogram of dry matter eaten

COARSE FODDERS		CONCENTRATES	
	Calories.		Calories.
Timothy hay.....	782	Maize meal.....	1,434
Red clover hay.....	962	Hominy chop.....	1,365
Mixed hay.....	980	Wheat bran.....	1,177
Alfalfa hay.....	1,169	Grain mixture No. 1.....	1,327
"Grass hay".....	1,045	Grain mixture No. 2.....	1,141
Rowen.....	958	Beet molasses.....	988
Meadow hay.....	1,254	Starch.....	1,248
Maize stover.....	1,065	Peanut oil.....	1,727
Barley straw.....	877	Wheat gluten.....	2,294
Oat straw.....	1,014		
Wheat straw.....	1,138		
Extracted straw.....	1,160		
Clover hay.....	932		

III. NET ENERGY VALUES AND THEIR COMPUTATION

The method of estimating the nutritive values of the feeding stuffs consumed by farm animals which has been current for many years may from one point of view be characterized in a broad way as a chemical method. On the basis of the fundamental investigations of Henneberg and Stohmann (21, 22) in the early sixties, it sought to determine the amounts of protein, carbohydrates, and fat contained in feeding stuffs in a digestible form, assuming that the groups thus determined had the same physiological values in the nutrition of herbivora as had the corresponding substances in the food of man and carnivora. It is a well-recognized fact, however, that our information regarding both the qualitative and quantitative composition of feeding stuffs is even yet very meager. Moreover, our knowledge of the physiological functions of their ingredients is even more defective, so that, as Kellner (24, p. 15) points out, the advances in our knowledge of the chemistry of plants have not led to a corresponding increase in our knowledge of their nutritive values and have left the methods for the analysis of feeding stuffs largely untouched.

Kellner appears to have been the first to attempt any practical application of the conception of the feed as a source of energy to the body. In 1880, in his investigations upon the relations between muscular activity and metabolism in the horse (23), he determined the additional amount of work which the animal was able to perform as a result of the addition to his rations of starch and of fat. He expressed his results in terms of the percentage of the energy of the starch or fat which was recovered as useful work and called attention to the desirability of determinations of the heats of combustion of nutrients and feeding stuffs. Sixteen years later, after Rubner (40, 41) had published his fundamental work on the replacement values of nutrients and Zuntz and his associates (30, 54) had begun their investigations on the metabolism of the horse from the standpoint of energy, Kellner was able to return to the subject and undertake those extensive investigations with cattle (cited on previous pages) upon which he based his well-known method of comparing feeding stuffs on the basis of their so-called starch values. These are in reality energy values, and, so far as they are the results of direct determinations, they were obtained by substantially the same general experimental methods used in our own investigations, although direct determinations of the heat production were not included.

VALUES DIRECTLY DETERMINED

The net energy value of a feeding stuff, as stated in the introductory paragraphs, is the energy which remains after deducting from its total chemical energy the two classes of losses which have been discussed in the first two sections of this article—viz, the losses of chemical energy

in the excreta and the increased heat production consequent upon the consumption of the feed. For example, the alfalfa hay consumed by steer E in experiment 208 contained per kilogram of dry matter 4,408 Calories of chemical energy. From the results reported in Tables III and X its net energy value, computed from the average results of periods 4, 5, and 6, is as follows:

Net energy value of alfalfa hay per kilogram of dry matter

	Calories.	Calories.	Calories.
Total chemical energy			4,408
Losses of chemical energy:			
In feces	2,062		
In urine	243		
In methane	266		
Total		2,571	
Increased heat production		1,202	
Total losses			3,773
Net energy value			635

Computed in practically this way, by subtracting from the gross energy the average losses of chemical energy recorded in Table IV and the average energy expenditure consequent upon the consumption of the feeding stuff as given on page 482, the average net energy values of the feeding stuffs used in these experiments are as follows:

Net energy values of feeding stuffs per kilogram of dry matter

Feeding stuff.	Gross energy.	Losses of chemical energy.	Energy expended in feed consumption.	Net energy values.
	Calories.	Calories.	Calories.	Calories.
Timothy hay	4,518	2,664	782	1,072
Red clover hay	4,462	2,461	962	1,039
Mixed hay	4,393	2,479	980	934
Alfalfa hay ^a	4,372	2,451	1,169	752
Maize stover	4,332	2,380	1,065	887
Maize meal	4,442	1,115	1,434	1,893
Wheat bran	4,532	2,021	1,177	1,334
Grain mixture No. 1	4,685	1,621	1,327	1,737
Grain mixture No. 2	4,609	1,620	1,141	1,848
Hominy chop	4,709	1,187	1,365	2,157

^a Includes alfalfa meal.

Kellner's results when put into the same form are as follows:

Net energy values of feeding stuffs per kilogram of dry matter: Kellner's results

Feeding stuff.	Gross energy.	Losses of chemical energy.	Energy expended in feed consumption.	Net energy values.
	Calories.	Calories.	Calories.	Calories.
Meadow hay	4,433	2,260	1,254	919
Oat straw	4,436	2,848	1,014	574
Wheat straw	4,444	3,062	1,138	244
Extracted straw	4,147	1,013	1,160	1,974
"Grass hay" ^a			1,045	803
Rowen ^a			958	747
Barley straw ^a			877	747
Clover hay ^a			932	811
Starch	4,152	1,101	1,248	1,803
Peanut oil	9,457	4,165	1,727	3,565
Wheat gluten	5,579	1,974	2,096	1,509
Beet molasses	3,743	945	988	1,810

^a As estimated on page 478.

Very striking is the relatively low value for alfalfa hay, due in part to somewhat large losses in the excreta but chiefly to its marked effect in stimulating the metabolism. It is needless to add that this loss does not affect its special value as a source of protein, but as a source of energy it appears to have been distinctly inferior to timothy hay or even to maize stover.

APPLICATION OF RESULTS TO OTHER FEEDING STUFFS

It is obviously impracticable to apply the laborious methods of respiration and calorimeter experiments to all the vast number of feeding stuffs now in use. It is necessary to select a few typical representatives of different groups and to endeavor to apply the results obtained as well as possible to other similar materials. This Kellner sought to do in his later and as yet unpublished experiments. In the practical application of his results, however, Kellner failed to free himself from the older point of view. Aside from what seems to us the unfortunate and unnecessary concession to established usage involved in expressing energy values in terms of matter, he approached the whole problem, as was quite natural, along the lines of the prevailing chemical methods. Determining first the net energy values of the simple nutrients, he applied these values to the digestible nutrients of feeding stuffs and found that in most cases the resulting energy values were materially higher than those obtained by direct experiments on animals. In the case of coarse fodders this deficit in the observed energy values was found to be approximately proportional to the total content of crude fiber, and by subtracting from the computed energy value 1.36 Calories per gram of total crude fiber results were obtained corresponding fairly well to those directly observed.

For finer materials like chaff, presumably requiring a less expenditure for mastication, 0.70 Calorie per gram of total crude fiber is deducted. For green forage containing 16 per cent or more of crude fiber the same deduction is made as for dry forage and for that containing 4 per cent or less of crude fiber, the same as for chaff, while between these limits a sliding scale is used (24, 1905, p. 593-594). For concentrates a factor (Wertigkeit) is estimated from the direct results on similar feeds by which the energy value computed from the digestible nutrients is multiplied to obtain the actual value.

The method of computation just outlined is not only somewhat complicated but is essentially based on the older view which regarded the feed in the light of a source of matter to the body. The digestible protein, carbohydrates, and fat are still the basis of the calculation, although certain more or less empirical corrections are applied to their computed effects. The energy content of a feeding stuff, however, is just as definite a quantity as its content of protein, carbohydrates, or fats, and it is entirely possible to trace the distribution of that energy in the body quite independently of any knowledge of the chemical composition of the materials. Not only so, but we believe that in discussing energy values there are distinct advantages as regards simplicity, and perhaps also as regards accuracy, in cutting loose entirely from the conventional data regarding chemical composition and digestion coefficients, as has been done in reporting our experiments on preceding pages, and in dealing directly with quantities of energy.

In making this statement we would by no means be understood to stigmatize comparisons based on chemical methods as either valueless or superfluous. The problems of nutrition are too complex and too difficult for us to refuse any light that can be thrown on them by any method, and the energy relations touch only one phase of them. The point is that in whatever degree their energetic aspects can be separated from their chemical aspects, to that extent we possess two independent methods of approach to them.

COMPUTATION OF NET ENERGY VALUES

The computation from the results of metabolism experiments or from the data of ordinary feeding tables in the manner just indicated of the net energy value of a feeding stuff which has not been the subject of direct experimental investigation with the respiration apparatus or calorimeter may be made a comparatively simple matter. The net energy value is equal to the metabolizable energy minus the energy lost as heat. It was shown on pages 450-451 that the metabolizable energy may be determined experimentally without special difficulty and with a good degree of accuracy by means of the ordinary metabolism experiment in which the energy of the feed, feces, and urine is directly determined and that

of the methane estimated from the amount of carbohydrates digested. When this is not practicable, it was further shown that the metabolizable energy may be estimated from the total digestible organic matter by the use of the factors given on pages 451-453. In one or other of these ways it is not difficult to compute approximately the metabolizable energy of the more common feeding stuffs, while the subtraction from this of the average energy expenditure due to feed consumption will give the net energy value. To illustrate, E. W. Allen,¹ gives the following data for average alfalfa hay, oat straw, and wheat bran:

Percentage of dry matter and digestible food ingredients of feeding stuffs

	Alfalfa hay.	Oat straw.	Wheat bran.
Total dry matter.....	91.6	90.8	88.5
Digestible:			
Protein.....	10.58	1.20	12.01
Carbohydrates.....	37.33	38.64	41.23
Fats.....	1.38	0.76	2.87
Total digestible.....	49.29	40.60	56.11

The sum of the digestible protein, carbohydrates, and fat equals, of course, the total digestible organic matter, irrespective of its chemical composition. Each gram of digestible organic matter, according to the averages on pages 451-453, would contain 3.5 Calories of metabolizable energy in the coarse fodders and 3.9 Calories in the bran. The average losses of energy in heat production per kilogram of feed would be the amounts shown on page 482 reduced to the average water content of the feed, as follows:

Alfalfa hay $1,169 \times 0.916 = 1,071$ Calories.
 Oat straw $1,014 \times 0.908 = 921$ Calories.
 Wheat bran $1,138 \times 0.885 = 1,007$ Calories.

The computation of the net energy values is therefore as follows:

Alfalfa hay (3.5 Calories $\times$ 492.9) - 1,071 Calories = 654 Calories per kilogram = 29.7 T. per 100 pounds.
 Oat straw (3.5 Calories $\times$ 406.0) - 921 Calories = 500 Calories per kilogram = 22.7 T. per 100 pounds.
 Wheat bran (3.9 Calories $\times$ 561.1) - 1,007 Calories = 1,181 Calories per kilogram = 53.6 T. per 100 pounds.

The methods of computation just illustrated are perhaps open to the charge of being to a degree summary and empirical. The idea of basing such computations on the energy values of the single ingredients may be fundamentally more scientific, but unfortunately at present it is an impracticable ideal on account of our deficient knowledge of the chemistry of feeding stuffs and of the physiological values of their ingredients. While investigation along both these lines is highly important and desirable, yet for a long time to come the data on which to base the practice of stock feeding will have to be obtained by more direct even

¹ Allen, E. W., The feeding of farm animals. U. S. Dept. Agr. Farmers' Bul. 22 (rev.), p. 8-9. 1901.

if less fundamental methods. Kellner's scheme recognizes this fact and his deduction for crude fiber and his factors for relative values (Wertigkeit) are at bottom simply a method of applying the aggregate net results on typical feeding stuffs to other materials. The method here proposed seeks to do exactly the same thing more directly and simply, relating the energy content and the necessary deductions to the total dry matter or total digestible matter of the feeding stuff, independently of its chemical composition. It is true that the data for so doing are somewhat meager, but, except as Kellner has utilized unpublished data in the formulation of his tables, they are just as abundant in the one case as in the other. It is greatly to be regretted that Kellner's results have not yet been published in full. When they become available they will doubtless greatly broaden the basis for such computations.

SUMMARY

There are reported the results of 76 experiments with the respiration calorimeter upon nine steers in which the balance of matter and of energy was determined.

The losses of feed energy from the animal are of two classes: (1) Losses of unused chemical energy in the feces, urine, and methane; and (2) losses in the form of heat due to the increased metabolism consequent upon the ingestion of feed.

(1) LOSSES OF CHEMICAL ENERGY.—The losses of energy in methane and urine were relatively greater on light than on moderately heavy rations.

Neither the losses of energy in the feces nor the total losses showed a distinct relation to the amount of feed consumed.

Individual differences between animals had no very material influence on the losses of chemical energy.

The losses of energy in methane may be computed approximately from the amount of total carbohydrates digested.

The metabolizable energy per kilogram of digested organic matter showed but slight variations within the same class of feeding stuffs.

(2) LOSSES OF HEAT CONSEQUENT UPON FEED CONSUMPTION.—The heat production is notably greater during standing than during lying, and the difference is greater on heavy than on light rations.

The increment of heat production during standing is affected by the individuality of the animal and by the kind of feed consumed.

An approximate partial analysis of the heat production of the animal into its principal factors is attempted.

The average energy expenditure consequent upon the consumption of 1 kg. of dry matter is reported for 11 different feeding stuffs.

The expenditure of energy arising from the consumption of the coarse feeds is not on the whole materially greater than in the case of the concentrates.

The increased muscular work of the digestive organs appears to be a relatively small factor of the increased heat production.

A scrub steer showed a somewhat greater increment of metabolism consequent upon feed consumption than did a pure-bred beef animal.

(3) NET ENERGY VALUES.—A summary of the average net energy values obtained in these experiments for 11 different feeding stuffs is given.

A simple method is outlined for computing net energy values, in the absence of direct determinations, from metabolism experiments or from the data of ordinary feeding tables.

LITERATURE CITED

- (1) ARMSBY, H. P.
1898. The maintenance ration of cattle. Penn. Agr. Exp. Sta. Bul. 42, 188 p., 18 pl.
- (2) ———
1903. Principles of Animal Nutrition... 614 p. New York.
- (3) ———
1904. The respiration calorimeter at the Pennsylvania experiment station. In Exp. Sta. Rec., v. 15, no. 11, p. 1037-1050, fig. 11-12, pl. 4-7.
- (4) ———
1908. Investigations in animal nutrition. U. S. Dept. Agr. Bur. Anim. Indus. 23d Ann. Rpt., 1906, p. 263-285, fig. 2-3, pl. 12-14.
- (5) ———
1913. A comparison of the observed and computed heat production of cattle. In Jour. Amer. Chem. Soc., v. 35, no. 11, p. 1794-1800.
- (6) ———
1913. Food as body fuel. Penn. Agr. Exp. Sta. Bul. 126, p. 59-68.
- (7) ——— and FRIES, J. A.
1903. The available energy of timothy hay. U. S. Dept. Agr. Bur. Anim. Indus. Bul. 51, 77 p., 2 pl.
- (8) ———
1905. Energy values of red clover hay and maize meal. U. S. Dept. Agr. Bur. Anim. Indus. Bul. 74, 64 p.
- (9) ———
1908. The available energy of red clover hay. U. S. Dept. Agr. Bur. Anim. Indus. Bul. 101, 64 p.
- (10) ———
1910. The influence of type and of age upon the utilization of feed by cattle. Penn. Agr. Exp. Sta. Ann. Rpt. 1909/10, p. 324-606, 1 fig., 20 pl. See also U. S. Dept. Agr. Bur. Anim. Indus. Bul. 128, 245 p., 17 fig., 3 pl. 1911.
- (11) ———
1913. The influence of standing or lying upon the metabolism of cattle. In Amer. Jour. Physiol., v. 31, no. 4, p. 245-253.
- (12) BENEDICT, F. G., and HOMANS, JOHN.
1911. A respiration apparatus for the determination of the carbon dioxide produced by small animals. In Amer. Jour. Physiol., v. 28, no. 1, p. 29-48, illus.
- (13) ———
1912. The metabolism of the hypophysectomized dog. In Jour. Med. Research, v. 25 (n. s. v. 20), no. 3, p. 409-501, 3 fig., 1 pl.
- (14) ——— and TALBOT, F. B.
1912. Some fundamental principles in studying infant metabolism. In Amer. Jour. Diseases of Children, v. 4, p. 129-136.
- (15) ———
1914. The Gaseous Metabolism of Infants. 168 p., illus. Washington. (Carnegie Inst. Washington, Pub. 201.)
- (16) BRAMAN, W. W.
1914. A study in drying urine for chemical analysis. In Jour. Biol. Chem., v. 19, no. 1, p. 105-113.
- (17) DAHM, KARL.
1910. Die Bedeutung des mechanischen Teils der Verdauungsarbeit für den Stoffwechsel des Rindes. In Biochem. Ztschr., Bd. 28, Heft 5/6, p. 456-503, 2 fig.
- (18) FINGERLING, G., KÖHLER, A., REINHARDT, FR., et al.
1914. Untersuchungen über den Stoff- und Energieumsatz wachsender Schweine. In Landw. Vers. Stat., Bd. 84, Heft 3/4, p. 149-230.

- (19) FRIES, J. A.
[1912.] The combustible gases excreted by cattle. *In* Orig. Commun. 8th Internat. Cong. Appl. Chem., v. 15, p. 109-119.
- (20) HEIDE, R. VON DER, KLEIN, —, and ZUNTZ, N.
1913. Respirations- und Stoffwechselversuche am Rinde über den Nährwert der Kartoffelschlempe und ihrer Ausgangsmaterialien. *In* Landw. Jahrb., Bd. 44, Heft 5, p. 765-844, pl. 2-5.
- (21) HENNEBERG, J. W. J.
1870. Neue Beiträge zur Begründung einer rationellen Fütterung der Wiederkäuer ... 457 p., 1 pl. Göttingen.
- (22) — and STOHMANN, F.
1860-64. Beiträge zur Begründung einer rationellen Fütterung der Wiederkäuer ... Hefte 1-2. Braunschweig.
- (23) KELLNER, OSKAR.
1880. Untersuchungen über den Zusammenhang zwischen Muskelthätigkeit und Stoffzerfall im thierischen Organismus. *In* Landw. Jahrb., Bd. 9, p. 651-688.
- (24) —
1905. Die Ernährung der landwirtschaftlichen Nutztiere ... 594 p. Berlin.
1912. — Aufl. 6, 640 p., front. Berlin.
- (25) — and KÖHLER, A.
1898. Untersuchungen über den Nahrungs- und Energie-Bedarf volljähriger gemästeter Ochsen. *In* Landw. Vers. Stat., Bd. 50, Heft 3/4, p. 245-296.
- (26) —
1900. Untersuchungen über den Stoff- und Energie-Umsatz des erwachsenen Rindes bei Erhaltungs- und Produktionsfutter. *In* Landw. Vers. Stat., Bd. 53, 474 p.
- (27) — and others.
1896. Untersuchungen über den Stoff- und Energie-Umsatz volljähriger Ochsen bei Erhaltungsfutter. *In* Landw. Vers. Stat., Bd. 47, Heft 4/5, p. 275-331.
- (28) KÜHN, GUSTAV, GERBER, FRANZ, et al.
1883. Versuche über die Verdaulichkeit der Weizenkleie und deren Veränderung durch verschiedene Arten der Zubereitung und Verabreichung sowie über die Verdaulichkeit des Wiesenheu's im trockenen und angefeuchteten zustande. *In* Landw. Vers. Stat., Bd. 29, p. 1-214.
- (29) — THOMAS, A., and others.
1894. Fütterungs- und Respirations-Versuche mit volljährigen Ochsen. *In* Landw. Vers. Stat., Bd. 44, p. 257-581, 2 fig., 1 pl.
- (30) LEHMANN, FRANZ, HAGEMANN, O., and ZUNTZ, N.
1894. Zur Kenntniss des Stoffwechsels beim Pferd. *In* Landw. Jahrb., Bd. 23, p. 125-165.
- (31) LUSK, GRAHAM.
1913. The cause of the specific dynamic action of protein. *In* Arch. Internat. Med., v. 12, no. 5, p. 485-487.
- (32) —
1913. The influence of foodstuffs and their cleavage products upon heat production. *In* Trans. Internat. Cong. Hyg. and Demog., 1912, v. 2, pt. 2, p. 400-406. Discussion, p. 406-409.
- (33) —
1914. The specific dynamic action of the foodstuffs. *In* Jour. Amer. Med. Assoc., v. 63, no. 10, p. 824-827.
- (34) — and RICHE, J. A.
1912. The influence of mixtures of foodstuffs upon metabolism. *In* Jour. Biol. Chem., v. 13, no. 2, p. 185-207.
- (35) —
1912. The influence of the ingestion of amino-acids upon metabolism. *In* Jour. Biol. Chem., v. 13, no. 2, p. 155-183.
- (36) —
1912. Metabolism after the ingestion of dextrose and fat, including the behavior of water, urea and sodium chloride solutions. *In* Jour. Biol. Chem., v. 13, no. 1, p. 27-47.
- (37) MARKOFF, J.
1911. Untersuchungen über die Gärungsprozesse bei der Verdauung der Wiederkäuer. *In* Biochem. Ztschr., Bd. 34, Heft 3/4, p. 211-232, 2 fig.

- (38) MARKOFF, J.
1913. Fortgesetzte Untersuchungen über die Gärungsprozesse bei der Verdauung der Wiederkäuer und des Schweines. *In* Biochem. Ztschr., Bd. 57, Heft 1/2, p. 1-69.
- (39) PAECHTNER, J.
1909. Respiratorische Stoffselforschung und ihre Bedeutung für die Nutztierhaltung und Tierheilkunde mit einem Beitrag zur Kenntnis vom Lungengaswechsel des Rindes. 64 p., 4 pl. Berlin.
- (40) RUBNER, MAX.
1883. Die Vertretungswerte der hauptsächlichsten organischen Nahrungstoffe im Thierkörper. *In* Ztschr. Biol., Bd. 19 (n. F. Bd. 1), p. 313-396.
- (41) —
1886. Bestimmung isodynamer Mengen von Eiweiss und Fett. *In* Ztschr. Biol. Bd. 22 (n. F. Bd. 4), p. 40-55.
- (42) SCHLOSSMANN, ARTHUR, and MURSCHHAUSER, HANS.
1910. Der Grundumsatz und Nahrungsbedarf des Säuglings gemäss Untersuchungen des Gasstoffwechsels. *In* Biochem. Ztschr., Bd. 26, Heft 1/2, p. 14-40.
- (43) —
1911. Über den Einfluss mässiger Temperaturschwankungen der umgebenden Luft auf den Respiratorischen Stoffwechsel des Säuglings. *In* Biochem. Ztschr., Bd. 37, Heft 1/2, p. 1-22.
- (44) TANGI, FRANZ.
1905. Beiträge zur Futtermittel lehre und Stoffwechselphysiologie der landwirtschaftlichen Nutztiere. *In* Landw. Jahrb., Bd. 34, Heft 1, p. 1-92.
- (45) — and WEISER, STEPHAN.
1906. Zur Kenntnis des Nährwertes einiger Heuarten. *In* Landw. Jahrb., Bd. 35, Heft 1/2, p. 159-223.
- (46) USTJANZEW, W.
1911. Die energetischen Äquivalente der Verdauungsarbeit bei den Wiederkäuern (Schafe). *In* Biochem. Ztschr., Bd. 37, Heft 5/6, p. 457-476.
- (47) VÖLTZ, WILHELM, PAECHTNER, JOHANNES, and BAUDREXEL, AUGUST.
1913. Über den Futterwert der Kartoffelschlempe, ihres Ausgangsmaterials und über sog. spezifische Wirkungen der Futterstoffe. *In* Landw. Jahrb., Bd. 44, Heft 5, p. 685-764.
- (48) —, et al.
1913. Vergleichende Untersuchungen über den Nährstoffbedarf bei der Mast des Rindes und des Schafes im späteren Verlauf des Wachstums. . . . *In* Landw. Jahrb., Bd. 45, Heft 3, p. 325-437, 1 fig., pl. 4-11.
- (49) WILLIAMS, H. B., RICHE, J. A., and LUSK, GRAHAM.
1912. Metabolism of the dog following the ingestion of meat in large quantity. *In* Jour. Biol. Chem., v. 12, no. 3, p. 349-376.
- (50) ZAITSCHEK, ARTHUR.
1906. Über die Zusammensetzung und den Nährwert des Kürbis. *In* Landw. Jahrb., Bd. 36, Heft 1/2, p. 245-258.
- (51) ZUNTZ, N.
1913. Berichtigung zu der Abhandlung "Zum Studium der Respiration und des Stoffwechsels der Wiederkäuer." *In* Landw. Vers. Stat., Bd. 83, Heft 3/4, p. 283-284.
- (52) ZUNTZ, N., and HAGEMANN, OSCAR.
1898. Untersuchungen über den Stoffwechsel des Pferdes bei Ruhe und Arbeit. *In* Landw. Jahrb., Bd. 27, Ergänzungsbd. 3, 438 p., 1 fig., 7 pl.
- (53) —, HEIDE, R. VON DER, KLEIN, —, et al.
1913. Zum Studium der Respiration und des Stoffwechsels der Wiederkäuer. *In* Landw. Vers. Stat., Bd. 79/80, p. 781-814, fig. 11.
- (54) ZUNTZ, N., and LEHMANN, C.
1889. Untersuchungen über den Stoffwechsel des Pferdes bei Ruhe und Arbeit. *In* Landw. Jahrb., Bd. 18, p. 1-156, pl. 1-3.

THE DETERMINATION OF AMMONIA NITROGEN IN STEER'S URINE.

By DONALD C. COCHRANE.

(From the Institute of Animal Nutrition of the Pennsylvania State College, in cooperation with the Bureau of Animal Industry of the United States Department of Agriculture.)

(Received for publication, September 27, 1915.)

In connection with certain metabolism experiments now in progress in this Institute, the determination of the nitrogen present in the urine of a steer as ammonium compounds and ammonia has become of considerable importance. Recurring peculiarities in the results obtained in some earlier work involving ammonia determinations led to the belief that the chloroform used in the urine as a preservative was inefficient, since in every case urine so treated showed an increase in the ammonia from day to day. Therefore it was planned to test out several preservatives especially as to their ability to prevent the breaking up of nitrogenous substances.

Numerous attempts have been made in this laboratory to differentiate between the nitrogen present in steer's urine as ammonium compounds and that present as ammonia. Braman,¹ however, has shown that practically all the ammonia nitrogen present is in the form of ammonium carbonate with possibly small quantities of ammonia. Simple aeration causes decomposition of ammonium carbonate, and while the addition of sodium chloride prevents a complete breaking up of the carbonate it has been found impossible to obtain a satisfactory separation.

The total quantity of urine excreted by a steer at one voiding was collected, immediately divided into four approximately equal parts, and preserved at about 10°C. during the period covered by analysis. The four samples were treated as follows:

¹ Braman, W. W., *Jour. Biol. Chem.*, 1914, xix, 105.

- I No preservative added.
- II Chloroform added to saturation.
- III Toluene added.

IV Sufficient N sulphuric acid added to render the sample slightly acid, using cochineal as an indicator.

The total nitrogen per cc. of urine was determined in all four samples using the Kjeldahl method. It was necessary, because of the dilution incident to the addition of the sulphuric acid to Sample IV, to compute the results obtained for ammonia nitrogen in terms of the original urine. In doing this, use was made of the total nitrogen in the original urine and the total nitrogen in the acid sample since these determinations were much more accurate than any measurement of volume available.

TABLE I.

Experiment 220, Period I, Steer K, Preliminary.
Ration 7.0 Kg. Clover Hay.

Nitrogen as ammonium compounds expressed as mg. nitrogen per cc. of original urine.

Sample.	1st day.*	2nd day.	3rd day.	4th day.	5th day.	6th day.	7th day.	8th day.	9th day.
	mg.	mg.	mg.	mg.	mg.	mg.	mg.	mg.	mg.
I	0.44	0.98	1.93			4.02	4.86	5.74	6.47
II		0.96	1.66			2.43	2.51	2.61	2.64
III		1.29	2.27	2.87		3.44	3.59	3.75	3.77
IV		0.44	0.40	0.44		0.52	0.57	0.59	0.68

* Total nitrogen 8.48 mg. per cc.

Nitrogen as ammonium compounds was determined by Steel's modification of Folin's method.² This method was decided upon because of the heavy precipitates of phosphates so often encountered in steer's urine.³ Duplicate determinations of ammonia nitrogen were made daily using the apparatus described by Folin,⁴ except that aeration was obtained through the use of a Crowell blower delivering about 7 liters per minute. Three hours were found to be sufficient for the recovery of the ammonia in all cases.

² Steel, M., *Jour. Biol. Chem.*, 1910-11, viii, 365.

³ Steel, M., and Gies, W. J., *ibid.*, 1908-09, v, 71.

⁴ Folin, O., *Ztschr. f. physiol. Chem.*, 1902, xxxvii, 161.

Table I shows the comparative results obtained upon each sample during nine successive days.

An examination of the table reveals rather astonishing results especially in view of the wide use of chloroform as a urinary preservative. The progressive and rapid increase in the ammonia nitrogen in Samples II and III, in which chloroform and toluene were used, would tend to cast doubt on the accuracy of ammonia determinations in the urine of herbivora reported by previous investigators.

The inhibiting action in the case of the sulphuric acid may be ascribed to the bactericidal action of the slight excess of acid⁵ over that necessary to neutralize the titratable alkalinity, or possibly to the formation of acid phosphates.⁶

To confirm the conclusions drawn from this experiment a further investigation of the action of sulphuric acid as a retardant of ammoniacal decomposition was undertaken. This covered a ten day period during which the total quantity of urine excreted each day was collected and sampled. Two samples of each daily urine were taken. One sample was treated with N H₂SO₄ as described above; the other was untreated. Both samples were kept in the ice chest until the analyses were made. In every case ammonia determinations were made as soon as possible after the close of the experimental day (6.00 p.m.) and in only two instances was the urine as much as forty hours old at the time of analysis. In the majority of cases fifteen hours, and in one case only two hours elapsed before the determinations were made.

Two composite samples were also made up covering the ten day period. One composite sample was untreated while to the other was added the quantity of sulphuric acid necessary to make the daily aliquot slightly acid.

The acid composite was found to be alkaline at the end of the eleventh day showing that some decomposition had taken place. The quantity of ammonia nitrogen present confirms this, there being twice as much in the acid composite as the average of the acid daily samples.

⁵ Endemann, H., *Chem. News*, 1880, xli, 152. Corfield, W. H., and Parks, L. C., *Treatment and Utilization of Sewage*, London, 3rd edition, 1887.

⁶ Rohé, G. H., *Textbook of Hygiene*, Philadelphia, 2nd edition, 1890, 357. Stutzer, A., *Ztschr. f. Hyg. u. Infektionskrankh.*, 1893, xiv, 116. Kleine, E., *Microorganisms and Disease*, New York, 2nd edition, 1886, 258.

Table II shows the comparative ammonia nitrogen in the ten different urines together with that in the corresponding composite sample.

TABLE II.
Experiment 220, Period I, Steer K.
Ration 7.0 Kg. Clover Hay.

Nitrogen in urine as ammonium compounds expressed as mg. nitrogen per cc. of original urine.

Sample.	1st day.	2nd day.	3rd day.	4th day.	5th day.	6th day.	7th day.	8th day.	9th day.	10th day.	Com- posite.
	mg.	mg.	mg.	mg.	mg.	mg.	mg.	mg.	mg.	mg.	mg.
Acid.....	0.28	0.25	(0.22*)	0.19	0.19	(0.21§)	0.27	0.34	0.13	(0.19*)	0.39
Untreated.....	0.48	0.46	(0.53)	0.32	0.32	(0.26)			0.19	(0.42)	0.77

TABLE III.

Experiment 220, Periods II and III, Steer K.
Rations 2.25 Kg. Clover Hay and 1.5 Kg. Clover Hay with 3.0 Kg. Maize Meal.
Nitrogen in urine as ammonium compounds expressed as mg. nitrogen per cc. of original urine.

Sample.	Period II.		Period III.	
	1st day.	Composite.	6th day.	Composite.
	mg.	mg.	mg.	mg.
Acid.....	0.21	0.32	(0.57§)	1.95
Untreated....	0.40	1.71	(0.64§)	

* Urine about 40 hours old when determinations were made.

§ Determinations made immediately at close of experimental day.

A comparison of the ammonia nitrogen in the acid with that in the untreated urine furnishes a full confirmation of the results shown in Table I. In every case there is much more nitrogen present as ammonia in the untreated than in the corresponding acid sample.

In order to be sure that sufficient sodium hydroxide was added to neutralize the slight excess of sulphuric acid and also liberate all ammonia, the quantity added was varied with the results in Table IV.

A variation from 0.5 to 1.0 gram of NaOH makes no appreciable difference in the quantity of ammonia liberated as shown in Table IV.

TABLE IV.

The Effect of Variations in the Quantity of NaOH on the Ammonia Determinations.

NaOH	Nitrogen.		
	Urine 1514.	Urine 1516.	Urine 1556.
gm.	mg.	mg.	mg.
0.5	1.18	1.08	1.12
0.75	1.13	0.98	
1.0			1.12

An examination of the results obtained on the acid and on the untreated composite sample, Table II, shows the same relative increase in ammonia as was found in the case of the daily urines. That decomposition took place even in the acid composite is shown by comparing it with the average of the acid daily samples from which it was made.

A composite of a series of urines, Table III, Period II, containing a slightly greater quantity of ammonia, treated as above showed an even greater difference between the acid and the untreated sample and about the same increase over the average of the acid daily urines from which it was made.

CONCLUSIONS.

1. Figures for nitrogen as free ammonia in the urine of cattle are unreliable because of the decomposition of ammonium carbonate.
2. Figures for total ammonia nitrogen are worthless unless special precautions are taken to overcome the rapid ammoniacal decomposition.
3. Chloroform and toluene fail to prevent the breaking up of the nitrogenous compounds.
4. Sulphuric acid when added to the urine of a steer in sufficient quantity to fix the ammonia present as carbonate and to slight

excess retards decomposition to such an extent as to allow time for analysis.

5. All ammonia determinations must be made on daily samples of urine because the sulphuric acid does not completely stop decomposition in a composite sample.

BULLETIN NO. 142

NET ENERGY VALUES FOR RUMINANTS*

BY HENRY PRENTISS ARMSBY AND J. AUGUST FRIES

INTRODUCTION.

Food the Fuel of the Body.

In a previous bulletin of this Station¹ it was shown from the results of experiments here and elsewhere that the food of man and of animals is in a very real sense the fuel of the body. When taken into the organism it undergoes a process of oxidation, or burning, more or less like that to which the fuel of an engine is subject, and in both cases the chemical energy contained in the fuel is changed into other forms, especially heat and mechanical work.

Not only so but it was also shown that the transformations of chemical energy into heat and work in the animal body take place according to the same general laws and with the same equivalencies as in artificial motors and in lifeless matter generally. The great law of the conservation of energy rules in the animal mechanism, whether in man, carnivora, or herbivora, just as in the engine. The body neither manufactures nor destroys energy. All that it gives out it gets from its food and all that is supplied in its food is sooner or later recovered in some form. We are fully justified, therefore, in speaking of the food as body fuel, and in our studies of its utilization we may be confident that any food energy which does not reappear in the form of heat or work has not been lost but has been stored up in the body as the chemical energy of meat, fat, etc., which may later serve to supply energy to the human body when consumed as food by man.

* Investigations under the Adams Act in co-operation with the Institute of Animal Nutrition and the Bureau of Animal Industry of the United States Department of Agriculture.

¹ Bulletin No. 126; Food as Body Fuel.

Feeding Stuffs of Unequal Value as Fuel

The statements of the last paragraph must not be understood as asserting that all feeding stuffs are equally valuable as sources of energy.

It is well known that such is not the case with the fuels used for artificial motors but that they differ widely as regards the gross amount of energy which they contain. In this respect feeding stuffs differ much less than do fuels. Thus, in the experiments whose results are recorded in Table 2, the gross energy of the several feeding stuffs used ranged from 198 Therms to 205 Therms per hundred pounds. In the case of the oil meals the maximum is somewhat higher. The gross energy contained in a feeding stuff is determined by burning a sample of the substance completely in compressed oxygen and measuring the amount of heat given off.

With the feed of the animal, as with the fuel of the power plant, however, it is not the gross amount of energy contained in it which determines its value but the amount which it is possible to get out of it and convert into other forms. Neither in the power plant nor in the animal is it possible to recover in useful forms all the energy of the material burned, and the relative values of fuels or of feeding stuffs as sources of energy depend quite as much upon the extent of the unavoidable losses in transformation as upon the amount originally present.

Sources of Loss.

The losses of energy which a fuel or a feeding stuff suffers in the process of conversion are of two general kinds:

First, part of the material may fail to be burned at all. In the case of the power plant, portions of unburned fuel may be lost in the ashes, either by dropping through a faulty grate or through being surrounded by slack and so protected from combustion, while still other portions may be converted into combustible gases which in part escape unburned through the stack. Similarly, certain portions of the feed of an animal escape digestion and reappear in the feces unburned. In herbivorous animals, such as cattle, sheep and horses, the losses in this way may be very considerable. With

roughage it seldom falls below 40 per cent. for ruminants and 50 per cent. for the horse, while in the case of concentrates the losses in this way may be stated roughly at from 10 to 30 per cent. for ruminants and up to 40 per cent. for the horse. The urine likewise carries off smaller amounts of partially burned material which constitute another source of loss. Moreover, there is more or less production of combustible gases by the animal, corresponding to the loss of unburned combustible gases through the flue in the case of the power plant. These gases consist chiefly of methane (marsh gas) produced in the digestive tract by the fermentation of its contents. The loss in this way amounts, in ruminants, to from 5 to 12 per cent. and in the horse to from 1 to 2 per cent.

In all these various ways, part, and sometimes a considerable part, of the energy of a feeding stuff escapes from the body still in the form of chemical energy.

Second. The consumption of feed sets in motion various processes which were not active in the fasting animal and whose performance consumes part of the energy derived from the combustion of the digestible portion of the feed.

In the first place, more or less muscular work is required for the mastication of the feed and its movement through the digestive tract. The case is somewhat like that of a boiler whose firebox is fed by a mechanical stoker. A certain fraction of the steam produced by the coal is used up in running the stoker and is therefore lost so far as the operation of the main engine is concerned. To use another illustration the case is somewhat as if a gasoline engine had to expend part of its power in pumping its supply of gasoline from a lower level.

Furthermore, it appears to be well established that the digestible substances taken up from the alimentary tract act as a direct stimulus to the combustions going on in the body, that is, that the body may burn up more material simply because a larger supply is available, while there is some evidence that an increase in the feed consumed tends to stimulate the minor incidental movements of the animal, or, in other words, to render the animal more restless, especially when standing.

In all, a not inconsiderable proportion of the energy mobilized in the combustion of the feed is converted, directly or indirectly, into heat which is radiated or otherwise lost from the body and is not available for the physiological functions of the animal.

Net Energy Values.

In the two ways just described much of the gross energy of its feed escapes from the grasp of the body, some of it going into the manure heap, some escaping in the gases given off, and some being finally expended simply in warming the surroundings of the animal. The remainder constitutes the *net energy value* of the feed. It is the part of the feed energy which can be utilized to run the bodily machine, while if more net energy is supplied in the feed than is required for this purpose the surplus may be stored up in the form of a gain of flesh or fat or both, or in the milk produced, which may later serve as fuel for the human machine.

EXPERIMENTAL RESULTS.

One of the objects of the investigations in animal nutrition which have been carried on here for a number of years past has been to ascertain the net energy values of feeding stuffs and to measure the various factors on which they depend. The experiments have been exclusively on cattle, nine different steers having been used in all, their ages ranging from 11 to 60 months. All were typical beef animals with one exception. With the aid of the respiration calorimeter elsewhere described, the losses of energy in the two ways just indicated on varying amounts of a number of different feeding stuffs and rations have been determined.

Losses in Excreta.

The amounts of energy lost in the visible excreta are quite simply determined by collecting and drying the feces and urine and measuring the heat produced when samples of them are completely burned, just as in the case of feeding stuffs.

To determine the energy lost in the combustible gases, an indirect method must be resorted to. By means of the respiration calorimeter it is possible to determine the amounts of carbon and hydrogen in these gases and thence to infer their nature. Our results in this respect agree with numerous earlier investigators in showing them to consist chiefly of methane (marsh gas), the heat of combustion of which is known. The losses of energy in this way can therefore be computed from the amount of carbon excreted in this form.

Metabolizable Energy.

The difference between the total energy of the feed and that carried off unused in the excreta shows how much of the former is capable of conversion into other forms in the body. This portion has been called the metabolizable energy, which means simply energy capable of transformation. It has sometimes been called fuel value because it measures the amount of heat which the feed is capable of producing in the body, but for various reasons the term is an unfortunate one.

The following figures, taken from an experiment on timothy hay, may serve to illustrate the general method of determining the metabolizable energy of a feeding stuff.

Metabolizable Energy of Timothy Hay

Energy of feed	
7.50 lbs. timothy hay.....	13.41 Therms
Energy of excreta	
11.15 lbs. Feces.....	5.47 Therms
14.71 lbs. Urine.....	0.61 Therms
0.18 lbs. Methane.....	1.10 Therms
Metabolizable energy	7.18 Therms
Total	6.23 Therms
Per pound	0.83 Therms

The results of a considerable number of determinations made here upon this plan, together with those of similar earlier experiments by Kellner & Köhler are shown in columns 3, 4 and 5 of

Table 2, p. 12. They are in most cases averages of several experiments, the full results being too voluminous for record here¹. No very material variations were found in different experiments on the same feeding stuff, neither the individuality of the animal nor the quantity of feed consumed, within the rather moderate limits of these trials, seeming to have any marked effect. The outstanding difference is that between roughage and concentrates, the losses from the former being much the greater. This difference is largely due to the greater losses in the feces in the former case; in other words, it is chiefly its low digestibility that causes a much smaller proportion of the energy of roughage to be metabolizable.

Metabolizable Energy of Digestible Organic Matter.

Since the differences between feeding stuffs as regards the amounts of metabolizable energy which they contain arise mainly from differences in the amounts of chemical energy lost in the feces, it follows that the metabolizable energy per unit of digestible organic matter may be expected to be much more uniform, and such is indeed the case to a rather remarkable degree. The results of a considerable number of experiments upon cattle, including those here reported, show the following range in the metabolizable energy per pound of digestible organic matter for roughage, concentrates and mixed rations.

Metabolizable Energy Per Pound of Organic Matter Digested by Cattle

	Roughage Therms	Concentrates Therms	Mixed Rations Therms
Maximum.....	1.697	2.200	1.869
Minimum.....	1.502	1.719	1.579
Mean.....	1.601	1.833	1.665

Feeding stuffs rich in protein or fat, especially the latter, naturally give higher values, as is indicated by the following results:

Metabolizable Energy Per Pound of Organic Matter Digested by Cattle

Palmnut meal	2.200 Therms
Wheat gluten	2.173 Therms
Flesh meal (for swine).....	2.554 Therms

¹ For more complete data, compare Jour. Agr. Research, 3 (1915), 435.

This general uniformity renders it possible to estimate the metabolizable energy of a feeding stuff by a simple multiplication when its content of digestible matter is known. For this purpose it appears that the following factors may be used for cattle and probably for other ruminants:

Roughage	1.588 Therms per lb.
Grains and similar feeds	
With less than 5% digestible fat...	1.769 Therms per lb.
With more than 5% digestible fat..	1.814 Therms per lb.
Oil meals, etc.	1.996-2.177 Therms per lb.

Losses of Energy Caused by Feed Consumption.

The chief object of the experiments was to determine the net energy values of feeding stuffs and rations in the sense already defined. For this purpose it was necessary to measure not only the amounts of energy which escaped unused in the solid, liquid and gaseous excreta, but also the energy cost of the increased body activity connected with the digestion and assimilation of the feed. In an animal at rest the energy thus expended finally takes the form of heat, and so a determination of the additional heat production caused by the feed furnishes a measure of the amount of energy lost in this way. For example, in the experiment used as an illustration on page 7, the animal, consuming 7.50 pounds of timothy hay per day, produced 7.79 Therms of heat. In the following period the hay ration was increased to 12.34 pounds and the heat production rose to 9.52 Therms. A simple computation, then, shows that each additional pound of hay increased the heat production by 0.3575 Therms; i. e., this amount of energy was expended in the digestion and assimilation of one pound of dry matter of the hay and served simply to warm the surroundings of the animal. From the results of our own experiments and those of Kellner already referred to, the following average figures for the energy expenditure caused by the consumption of one hundred pounds of dry matter of various feeding stuffs have been computed:

TABLE I. AVERAGE ENERGY EXPENDITURE BY CATTLE PER 100 POUNDS OF DRY MATTER EATEN.

	Experimenters ^a	Energy Expenditure Therms
ROUGHAGE		
Timothy hay	A & F	35.47
Red clover hay	A & F	44.13
Red clover hay	K & K	42.27
Mixed hay	A & F	44.45
Alfalfa hay	A & F	53.03
"Grass hay"	K & K	47.40
Meadow hay	K & K	56.88
Rowen	K & K	43.46
Corn stover	A & F	48.31
Barley straw	K & K	39.78
Oat straw	K & K	46.00
Wheat straw	K & K	51.62
Straw pulp	K & K	52.62
CONCENTRATES		
Corn meal	A & F	58.33
Hominy chop	A & F	61.92
Wheat bran	A & F	53.39
Grain mixture No. 1 ^b	A & F	60.19
Grain mixture No. 2 ^c	A & F	51.76
Cottonseed meal	K & K	44.36
Linseed meal	K & K	54.79
Peanut meal	K & K	45.68
Beet molasses	K & K	52.57
Starch	K & K	44.82
Peanut oil	K & K	56.61
Wheat gluten	K & K	78.34
		95.08

(a) In this and the following tables, A & F signifies Armsby & Fries and K & K, Kellner & Köhler.

(b) Wheat bran, 14.28 per cent.; corn meal, 42.86 per cent.; old process linseed meal, 42.86 per cent.

(c) Corn meal, 60 per cent.; crushed oats, 30 per cent.; old process linseed meal, 10 per cent.

Comparison of Roughage and Concentrates.

It has been more or less customary to regard the increased heat production which follows the consumption of feed as due to the additional work imposed on the digestive organs, somewhat as a man becomes warm in consequence of bodily exercise. Following out this idea it has been taught that the work of digestion is materially greater with coarse, woody feeds like hay, straw, corn fodder and the like than in the case of the more concentrated and highly digestible grains. The foregoing results show clearly that

this is not the case. While considerable differences between different feeding stuffs exist, the concentrates on the whole caused fully as great an expenditure of energy in heat production as did the coarse feeds, and it is evident that the mechanical work required in digestion is but a small part of its total energy cost. Alfalfa hay, for example, causes a much greater increase in the heat production than an equal amount of timothy hay, yet the mechanical work of digestion can hardly be imagined to be much different in the two cases. Corn meal seems to give rise to a still greater heat production, although the mechanical work involved would presumably be less rather than greater than with either alfalfa or timothy hay.

Factors of Heat Increment.

With cattle one considerable factor in the loss of energy as heat is the extensive fermentations in the paunch, which evolve heat just as do other fermentations outside the body. Evidence which cannot be detailed here, however, renders it probable that the greatest single factor is a direct stimulation of the processes of combustion in the body, partly by the presence of more fuel material in the blood and partly by specific stimulating substances derived from the feed. Alfalfa and corn meal in particular furnish instances in which this fanning up of the body combustions must apparently be attributed in part to such substances.

Net Energy Values.

But whatever may be the explanation of the considerable loss of energy consequent on feed consumption, its existence has been fully demonstrated in a large number of experiments on various species, including man, and the energy thus turned toward the production of superfluous heat, as well as that rejected in the excreta, must be deducted from the gross energy of a feeding stuff to obtain its net energy value. Combining the results recorded in Table 1, regarding the losses due to increased heat production, with those regarding the losses of chemical energy in the excreta, the net energy values of the different feeding stuffs were as shown in the last column of Table 2.

TABLE 2. NET ENERGY VALUES OF FEEDING STUFFS PER HUNDRED POUNDS OF DRY MATTER.

	Experi- menters	Gross energy	Losses of chemical energy in excreta	Metabo- lizable energy	Energy expended in feed con- sumption	Net energy values
ROUGHAGE						
Timothy hay.....	A & F	Therms 204.94	Therms 120.84	Therms 84.10	Therms 35.47	Therms 48.63
Red clover hay.....	A & F	202.40	111.63	90.77	44.13	46.64
Red clover hay.....	K & K	.....	.....	79.06	42.27	36.79
Mixed hay.....	A & F	199.27	112.45	86.82	44.45	43.37
Alfalfa hay.....	A & F	198.31	111.18	87.13	53.03	34.10
"Grass hay".....	K & K	.....	.....	83.83	47.40	36.43
Meadow hay.....	K & K	201.08	102.51	98.57	56.88	41.69
Rowen.....	K & K	.....	.....	77.34	43.46	33.88
Corn stover.....	A & F	196.50	107.96	88.54	49.31	40.23
Barley straw.....	K & K	.....	.....	73.67	39.78	33.89
Oat straw.....	K & K	201.22	129.19	72.03	46.00	26.03
Wheat straw.....	K & K	201.58	138.89	62.69	51.62	11.07
Straw pulp.....	K & K	188.11	45.95	142.16	52.62	89.54
CONCENTRATES						
Corn meal.....	A & F	201.49	50.58	150.91	58.33	92.58
Hominy chop.....	A & F	213.60	53.84	159.76	61.92	97.84
Wheat bran.....	A & F	205.57	91.67	113.90	53.39	60.51
Grain mixture No. 1..	A & F	212.51	73.53	138.98	60.19	78.79
Grain mixture No. 2..	A & F	209.06	73.48	135.58	51.76	83.82
Cottonseed meal.....	K & K	.....	.....	129.15 ^a	44.36	84.79
Linseed meal.....	K & K	.....	.....	137.72 ^a	54.79	82.93
Palmnut meal.....	K & K	.....	.....	124.57 ^a	45.68	78.89
Peanut meal.....	K & K	.....	.....	134.13 ^a	52.57	81.56
Beet molasses.....	K & K	169.80	42.88	126.92	44.82	82.10
Starch.....	K & K	188.35	49.95	138.40	56.61	81.79
Peanut oil.....	K & K	429.00	188.95	240.05	78.34	161.71
Wheat gluten.....	K & K	253.10	89.58	163.52	95.08	68.45

^a Estimated from digestible organic matter.

According to the foregoing figures the percentages of the gross energy of the different feeds which were rejected unused in the excreta or expended in digestion, etc., and the percentages available to the animal were as follows:

TABLE 3. DISTRIBUTION OF ENERGY OF FEEDS.

	Experi- menters	Rejected unused in excreta	Expended in digestion, etc. and converted into heat	Available to Animal
ROUGHAGE				
		%	%	%
Timothy hay.....	A & F	59	17	24
Clover hay.....	A & F	55	22	23
Mixed hay.....	A & F	57	22	21
Alfalfa hay.....	A & F	56	27	17
Meadow hay.....	K & K	51	28	21
Corn stover.....	A & F	55	25	20
Oat straw.....	K & K	64	23	13
Wheat straw.....	K & K	69	26	5
Extracted straw.....	K & K	24	28	48
CONCENTRATES				
Corn meal.....	A & F	25	29	46
Hominy chop.....	A & F	25	29	46
Wheat bran.....	A & F	45	26	29
Mixed grain ration No. 1..	A & F	35	28	37
Mixed grain ration No. 2..	A & F	35	25	40
Beet molasses.....	K & K	25	26	49
Starch.....	K & K	27	30	43
Peanut oil.....	K & K	44	18	38
Wheat gluten.....	K & K	35	38	27

Computation of Net Energy Values.

It is obviously impracticable to apply the laborious methods of respiration and calorimeter experiments to all the great variety of feeding stuffs now in use. It does appear possible, however, to select a few typical representatives of the different classes and to apply the results obtained upon them to other similar materials, much as is even yet done to a considerable extent with the results of digestion experiments. The somewhat complicated method used by Kellner for this purpose has already been described in Bulletin No. 71 of this Station as well as in Kellner's smaller textbook, of which an English translation entitled "The Scientific Feeding of Farm Animals" has lately been published¹. A simpler method, however, can be used. Extensive tables are available which show with more or less accuracy for a large number of feeding stuffs the digestible nutrients, the sum of which, of course, makes up the total digestible organic matter. It was shown on page 8, however, that the metabolizable energy per pound of digestible organic

¹ Kellner expresses the results in terms of so-called "starch values," which are really energy values and can equally well be expressed in Therms.

matter does not vary greatly in feeding stuffs of the same class, so that by multiplying the sum of the digestible nutrients by the proper factor a fairly close estimate of the total metabolizable energy can be secured. To get the net energy value it is only necessary to subtract from the latter the loss of energy in the form of heat.

Table 1 shows the amount of this loss in the case of a number of feeding stuffs. When direct determinations of it are not available, it is necessary to estimate it as well as possible from the results on similar feeding stuffs. It is true that the basis for such estimates is at present somewhat limited and it is to be regretted that so many of Kellner & Köhler's results still await full publication. On the other hand, however, the differences between different feeding stuffs in this respect are not nearly so great as has sometimes been assumed, so that the error involved in such estimates is not as serious as might otherwise be the case. As an illustration of the method of computation we may take average timothy hay, containing the following amounts of digestible matter:

<i>In 100 Pounds of Timothy Hay</i>		Pounds
Dry matter		88.4
Digestible		
Protein		3.0
Carbohydrates		42.8
Fat		1.2
Total digestible organic matter.....		47.0

According to the figures on page 9, each pound of digestible organic matter in roughage contains approximately 1.588 Therms of metabolizable energy, while Table 1 shows that each pound of dry matter of timothy hay causes a heat expenditure of 0.3547 Therms. The net energy value, therefore, of the 88.4 pounds of dry matter contained in 100 pounds of the hay would be:

Metabolizable energy...	$1.588 \text{ Therms} \times 47.0 = 74.64 \text{ Therms}$
Heat expenditure.....	$0.3547 \text{ Therms} \times 88.4 = 31.36 \text{ Therms}$
Net energy value.....	43.28 Therms

NET ENERGY VALUES OF AMERICAN FEEDING STUFFS

BY HENRY PRENTISS ARMSBY AND FRED SILVER PUTNEY.

Henry and Morrison¹ have recently published a very valuable compilation of American analyses of feeding stuffs and of the results of American digestion experiments, and on this basis have calculated the content of digestible nutrients (for ruminants) in a great variety of feeding stuffs.

With the permission of these authors, we have undertaken to compute from their tables the net energy values of the more important feeding stuffs in the manner illustrated in the last paragraph of the foregoing paper and with the results contained in the following table, which includes also the digestible (true) protein and the non-protein. In regard to this table it is to be remarked:

First, both the digestion coefficients used by Henry and Morrison and the data for the expenditure of energy due to feed consumption are derived exclusively from experiments on ruminants (in the latter case, on cattle). Consequently, the net energy values here computed are applicable to ruminants only and not to horses nor to swine.

Second, the table shows primarily the net energy values for maintenance or fattening. There seems good reason for believing, however, that they may be taken without serious error to represent also the net energy values for growth and at least the relative values for milk production.

Third, in comparing the figures for the various feeding stuffs, account should be taken of the differences in moisture content. Many of Henry and Morrison's averages for dry feeds show a remarkably low moisture content, tending to raise the suspicion that some of the analyses averaged were made on partially dried samples, although the authors state that every precaution was taken

¹ Feeds and Feeding, 15th Edition, pp. 633-666.

to exclude such cases from the compilation. It is evident at least that more study of the actual percentage of moisture in feeding stuffs as they are used in practice is much to be desired.

Fourth, Henry and Morrison's tables include only the crude protein ($N \times 6.25$). The amount of non-protein has been estimated from the crude protein by the writers on the basis of Kellner's averages.

AVERAGE DRY MATTER, DIGESTIBLE CRUDE PROTEIN, DIGESTIBLE TRUE PROTEIN, AND NET ENERGY VALUES PER 100 POUNDS FOR RUMINANTS.

	Dry matter	Digestible		Net energy value
		Crude protein	True protein	
DRIED ROUGHAGE				
<i>Hay and fodder from cereals</i>				
	Lbs.	Lbs.	Lbs.	Therms
Brome grass, smooth.....	91.5	5.0	3.5	40.83
Corn fodder (ears included, medium dry) ..	81.7	3.0	2.3	43.94
Corn stover (ears removed medium dry) ..	81.0	2.1	1.6	31.62
Millet, Hungarian	85.7	5.0	3.9	46.96
Mixed timothy and clover.....	87.8	5.3	3.2	41.07
Oat hay	88.0	4.5	3.9	32.25
Orchard grass	88.4	4.7	3.3	44.93
Red top	90.2	4.6	3.9	51.22
Timothy, all analyses	88.4	3.0	2.2	43.02
Timothy, before bloom	92.8	4.7	2.9	43.52
Timothy, early to full bloom.....	87.2	3.6	2.5	47.40
Timothy, late bloom to early seed.....	85.1	2.4	1.8	37.54
Timothy, nearly ripe	87.5	2.2	1.8	38.59
<i>Hay and fodder from legumes</i>				
Alfalfa, all analyses	91.4	10.6	7.1	34.23
Alfalfa, before bloom	93.8	15.4	10.3	36.23
Alfalfa, in bloom	92.5	10.5	6.7	32.33
Alfalfa, in seed	89.6	8.5	6.2	32.23
Clover, alsike	87.7	7.9	5.3	34.42
Clover, crimson	89.4	9.7	6.9	36.21
Clover, red, all analyses	87.1	7.6	4.9	38.68
Clover, red, before bloom	89.6	11.6	5.4	42.17
Clover, red, in bloom	86.1	8.1	5.3	39.12
Clover, red, after bloom	77.9	6.8	4.5	34.51
Clover, sweet, white	91.4	10.9	6.7	38.98
Cowpeas, all analyses	90.3	13.1	9.2	37.59
Cowpeas, before bloom	92.2	17.8	12.8	33.54
Cowpeas, in bloom to early pod.....	89.4	12.6	9.5	39.11
Soybeans	91.4	11.7	8.8	44.03
<i>Straws</i>				
Barley	85.8	0.9	0.6	36.61
Buckwheat	90.1	4.2	3.2	4.55
Oat	88.5	1.0	0.8	34.81
Rye	92.9	0.7	0.5	17.59
Wheat	91.6	0.7	0.3	7.22
FRESH GREEN ROUGHAGE				
<i>Green cereals, etc.</i>				
Barley fodder	23.2	2.3	2.0	14.08
Blue grass, Kentucky, before heading	23.8	3.7	2.8	14.82
Blue grass, Kentucky, headed out.....	36.4	2.8	2.2	17.77
Blue grass, Kentucky, after bloom	43.6	1.9	1.6	21.01
Buckwheat, Japanese	36.6	2.2	1.5	17.78
Cabbage	8.9	1.9	1.3	8.87
Cabbage, waste outer leaves.....	14.1	1.7	1.1	7.05

AVERAGE DRY MATTER, DIGESTIBLE CRUDE PROTEIN, DIGESTIBLE TRUE PROTEIN, AND NET ENERGY VALUES PER 100 POUNDS FOR RUMINANTS—Continued.

	Dry matter	Digestible		Net energy value
		Crude protein	True protein	
	Lbs.	Lbs.	Lbs.	Therms
Corn fodder, dent, all analyses.....	23.1	1.0	0.8	14.60
Corn fodder, dent, in tassel.....	14.9	1.1	0.8	9.52
Corn fodder, dent, in milk.....	19.9	1.0	0.8	13.64
Corn fodder, dent, dough to glazing.....	25.1	1.3	1.0	17.35
Corn fodder, dent, kernels glazed.....	26.2	1.1	0.8	16.74
Corn fodder, dent, kernels ripe.....	34.8	1.5	1.1	22.48
Corn fodder, flint, all analyses.....	20.7	1.0	0.8	13.53
Corn fodder, flint, in tassel.....	10.6	0.9	0.7	6.89
Corn fodder, flint, in milk.....	15.0	0.9	0.7	10.39
Corn fodder, flint, kernels glazed.....	21.0	1.0	0.8	13.49
Corn fodder, flint, kernels ripe.....	27.9	1.2	0.9	17.84
Corn fodder, sweet, before milk stage.....	10.0	0.8	0.6	7.82
Corn fodder, sweet, roasting ears or later..	20.3	1.2	0.9	13.38
Corn fodder, sweet, ears removed.....	21.5	1.0	0.8	14.26
Millet, Hungarian.....	27.6	1.9	1.1	17.24
Oat fodder.....	26.1	2.3	2.0	14.06
Orchard grass.....	29.2	1.7	1.1	15.81
Rape.....	16.7	2.6	1.7	13.07
Rye fodder.....	21.3	2.1	1.4	15.99
Sweet sorghum fodder.....	24.9	0.7	0.4	15.37
Timothy, before bloom.....	24.2	1.8	1.1	18.36
Timothy, in bloom.....	32.1	1.3	0.8	18.89
Timothy, in seed.....	46.4	1.5	1.0	26.36
Wheat fodder.....	27.4	2.8	1.9	18.75
<i>Green legumes</i>				
Alfalfa, before bloom.....	19.9	3.5	1.9	9.20
Alfalfa, in bloom.....	25.9	3.3	1.8	11.50
Alfalfa, after bloom.....	29.8	2.1	1.3	11.10
Clover, alsike.....	24.3	2.7	1.5	14.56
Clover, crimson.....	17.4	2.3	1.6	10.83
Clover, red, all analyses.....	26.2	2.7	1.7	15.87
Clover, red, in bloom.....	27.5	2.7	1.8	16.74
Clover, red, rowen.....	34.4	3.3	2.2	17.30
Cowpeas.....	16.3	2.3	1.7	10.42
Peas, Canada field.....	16.6	2.9	2.1	9.78
Soybeans, all analyses.....	23.6	3.2	2.4	12.53
Soybeans, in bloom.....	20.8	3.0	2.3	10.44
Soybeans, in seed.....	24.2	3.1	2.5	12.70
Vetch, hairy.....	18.1	3.5	2.4	11.95
<i>SILAGE</i>				
Corn, well-matured, recent analyses.....	26.3	1.1	0.6	15.90
Corn, immature.....	21.0	1.0	0.4	11.96
Corn, from frosted ears.....	25.3	1.2	0.6	14.27
Corn, from field-cured stover.....	19.6	0.5	0.3	8.98
Clover.....	27.8	1.3	0.8	7.26
Cowpeas.....	22.0	1.8	1.1	11.05
Soybeans.....	27.1	2.6	1.5	11.59
Sugar beet pulp.....	10.0	0.8	0.5	9.32

AVERAGE DRY MATTER, DIGESTIBLE CRUDE PROTEIN, DIGESTIBLE TRUE PROTEIN, AND NET ENERGY VALUES PER 100 POUNDS FOR RUMINANTS—Continued.

	Dry matter	Digestible		Net energy value
		Crude protein	True protein	
	Lbs.	Lbs.	Lbs.	Therms
<i>ROOTS, TUBERS AND FRUITS</i>				
Apple.....	18.2	0.4	0.1	15.92
Beet, common.....	13.0	0.9	0.1	7.84
Beet, sugar.....	16.4	1.2	0.4	11.20
Carrot.....	11.7	0.9	0.5	9.21
Mangels.....	9.4	0.8	0.1	5.68
Potatoes.....	21.2	1.1	0.1	18.27
Pumpkin, field.....	8.3	1.1	0.6	6.05
Rutabaga.....	10.9	1.0	0.3	8.46
Turnip.....	9.5	1.0	0.4	6.16
<i>GRAINS</i>				
<i>Cereal grains</i>				
Barley.....	90.7	9.0	8.3	89.94
Buckwheat.....	87.9	8.1	7.2	59.73
Corn, dent.....	89.5	7.5	7.0	89.16
Corn, flint.....	87.8	7.7	7.2	87.50
Corn and cob meal.....	89.6	6.1	5.7	75.80
Corn meal.....	88.7	6.9	6.4	88.75
Oats.....	90.8	9.7	8.7	67.56
Oat meal.....	92.1	12.8	11.5	86.20
Rye.....	90.6	9.9	9.0	93.71
Wheat, all analyses.....	89.8	9.2	8.1	91.82
Wheat, winter.....	89.1	8.7	7.7	91.66
Wheat, spring.....	89.9	9.2	8.1	91.41
<i>Leguminous seeds</i>				
Bean, navy.....	86.6	18.8	16.4	73.29
Cowpea.....	88.4	19.4	16.9	79.46
Pea, field.....	90.8	19.0	16.6	78.72
Pea meal.....	89.1	19.8	17.2	77.62
Peanut with hull.....	93.5	19.4	16.9	83.15
Peanut kernel.....	94.0	24.1	22.2	109.04
Soybean.....	90.1	30.7	27.3	81.29
<i>Oil seeds</i>				
Cotton seed.....	90.6	13.3	11.9	78.33
Flax seed.....	90.8	20.6	19.2	83.17
Sunflower seed.....	95.5	23.3	20.2	95.77
Sunflower seed with hulls.....	93.1	13.5	11.7	92.49
<i>DAIRY PRODUCTS</i>				
Buttermilk.....	9.4	3.4	3.4	13.32
Cow's milk.....	13.6	3.3	3.3	29.01
Skimmilk—centrifugal.....	9.9	3.6	3.6	14.31
Skimmilk—gravity.....	9.6	3.1	3.1	15.43
Skimmilk—dried.....	91.7	34.4	34.4	103.91
Whey.....	6.6	0.8	0.8	10.39
<i>BY-PRODUCTS</i>				
<i>Fermentation industries</i>				
Brewers' grains, dried.....	92.5	21.5	20.2	53.38
Brewers' grains, dried, below 25% protein..	91.8	18.7	17.5	50.93

AVERAGE DRY MATTER, DIGESTIBLE CRUDE PROTEIN, DIGESTIBLE TRUE PROTEIN, AND NET ENERGY VALUES PER 100 POUNDS FOR RUMINANTS—Continued.

	Dry matter	Digestible		Net energy value
		Crude protein	True protein	
	Lbs.	Lbs.	Lbs.	Therms
Brewers' grains, wet	24.1	4.6	4.4	14.53
Distillers' grains, dried, from corn	93.4	22.4	18.3	85.08
Distillers' grains, dried, from rye	92.8	13.6	11.1	56.01
Distillers' grains, wet	22.6	3.3	2.8	22.05
Malt	94.2	15.8	11.8	87.82
Malt sprouts	92.4	20.3	12.5	72.72
<i>Milling</i>				
Buckwheat bran	88.8	10.5	9.1	30.59
Buckwheat hulls	89.7	0.4	?	-7.69
Buckwheat middlings	88.0	24.6	20.8	72.19
Hominy feed	89.9	7.0	6.5	81.31
Rye bran	88.6	12.2	10.5	79.35
Wheat bran	89.9	12.5	10.8	53.00
Wheat middlings, flour	89.3	15.7	14.0	75.02
Wheat middlings, standard	89.6	13.4	12.0	59.10
<i>Oil extraction</i>				
Cocanut meal, low in fat	90.4	18.8	18.3	83.49
Cocanut meal, high in fat	92.3	18.4	18.0	100.31
Cottonseed hulls	90.3	0.3	?	9.92
Cottonseed meal, choice	92.5	37.0	35.4	93.46
Cottonseed meal, prime	92.2	33.4	32.0	90.00
Germ oil meal, corn	91.1	16.5	14.3	83.88
Linseed meal, new process	90.4	31.7	30.9	85.12
Linseed meal, old process	90.9	30.2	28.5	88.91
Palmnut cake	89.6	12.4	12.0	94.18
Peanut cake from hulled nuts	89.3	42.8	41.4	93.55
Peanut cake, hulls included	94.4	20.2	19.5	42.57
Soybean meal, fat extracted	88.2	38.1	37.3	99.65
Sunflower seed cake	90.0	32.0	29.1	88.87
<i>Starch manufacture</i>				
Gluten feed	91.3	21.6	20.1	80.72
Gluten meal	90.9	30.2	28.1	84.15
Starch feed, dry	90.7	11.2	9.2	77.46
Starch feed, wet	33.4	4.1	3.7	30.45
<i>Sugar manufacture</i>				
Molasses, beet	74.7	1.1	0.0	57.10
Molasses, cane or black strap	74.2	1.0	0.0	55.38
Molasses beet pulp	92.4	5.9	3.5	76.28
Sugar beet pulp, dried	91.8	4.6	0.7	75.87
Sugar beet pulp, ensiled	10.0	0.8	0.5	9.32
Sugar beet pulp, wet	9.3	0.5	0.5	8.99
<i>Packing house</i>				
Dried blood	90.3	69.1	68.6	68.12
Tankage				
Over 60% protein	92.6	58.7	55.6	93.04
55-60% protein	92.5	54.0	51.1	83.58
45-55% protein	92.5	48.1	45.5	72.96
Below 45% protein	93.5	37.6	35.6	54.16

COMPUTATION OF DAIRY RATIONS

By FRED S. PUTNEY AND HENRY PRENTISS ARMSBY

INTRODUCTION

For the method used in this bulletin, the authors wish to make acknowledgements to Professor H. E. Van Norman who developed it in Bulletin No. 114 of this station. The fundamental principles, upon which the tables herein are based, are explained by Dr. H. P. Armsby and J. A. Fries, in Bulletin No. 142 of this station, entitled "Net Energy Values for Ruminants."

FEEDING STANDARD

Maintenance Requirements. A maintenance ration for a dry dairy cow is the definite amount of food necessary daily to keep her alive, without giving any milk, gaining or losing in flesh or fat, growing a foetus, or doing work of any kind. A knowledge of the maintenance requirement for dairy cows is important, then, because it represents a fixed feeding charge for any specified animal. The following table shows the average amount of digestible true protein and net energy required per day for maintenance by cows of different weights:

Table 1.—Maintenance Requirement for Cows

Weight	Pounds Digestible True Protein	Therms Net Energy	Weight	Pounds Digestible True Protein	Therms Net Energy
750	.413	4.95	1225	.572	6.87
775	.422	5.06	1250	.580	6.96
800	.431	5.17	1275	.587	7.05
825	.440	5.28	1300	.596	7.15
850	.449	5.38	1325	.603	7.24
875	.457	5.49	1350	.611	7.33
900	.466	5.59	1375	.618	7.42
925	.475	5.70	1400	.626	7.51
950	.483	5.80	1425	.633	7.60
975	.491	5.90	1450	.641	7.69
1000	.500	6.00	1475	.648	7.78
1025	.508	6.10	1500	.655	7.86
1050	.517	6.20	1525	.662	7.95
1075	.525	6.30	1550	.670	8.03
1100	.533	6.39	1575	.677	8.12
1125	.541	6.49	1600	.684	8.21
1150	.548	6.58	1625	.691	8.29
1175	.557	6.68	1650	.698	8.38
1200	.565	6.78			

Requirements for Milk Production in Addition to Maintenance.

If a milking dairy cow is to keep up her flow of milk for some time she must be fed in addition to her maintenance requirement. In a general way, and within certain limits, her production will be in proportion to the amount that she eats over and above the maintenance ration. Each cow has inherited a limit to her milking ability. When this limit is reached additional food will not be used to make milk, but will go to increase her live weight. The food cost of the last few pounds of milk which a cow can be made to give is also expensive, because the amount of food required to produce one pound of milk increases rapidly as the limit of the milk-making ability is approached.

The following table shows the amounts of digestible true protein and net energy which should be added to the maintenance requirements in order to produce economically different amounts of milk of different qualities:

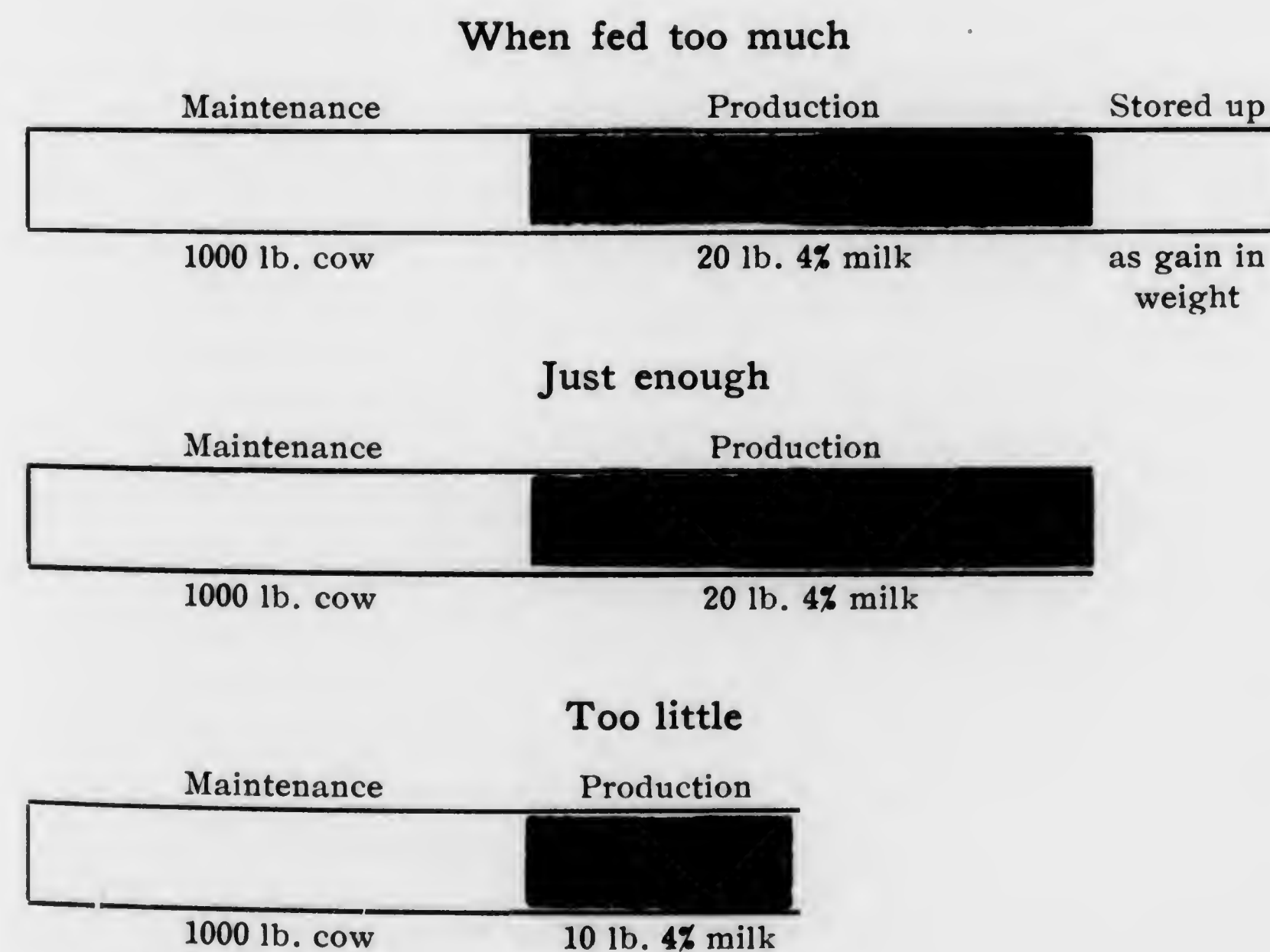
Table 2.—Requirements for Milk Production in Addition to Maintenance

For	2.5% milk		3% milk		3.5% milk		4% milk		4.5% milk	
	True Protein	Net Energy	True Protein	Net Energy	True Protein	Net Energy	True Protein	Net Energy	True Protein	Net Energy
1 lb. of milk	.041	.19	.043	.21	.045	.24	.049	.27	.052	.29
5 lb. of milk	.205	.95	.215	1.05	.225	1.20	.245	1.35	.260	1.45
10 lb. of milk	.410	1.9	.43	2.1	.45	2.4	.49	2.7	.52	2.9
15 lb. of milk	.615	2.85	.645	3.15	.675	3.6	.735	4.05	.78	4.35
20 lb. of milk	.82	3.8	.86	4.2	.90	4.8	.98	5.4	1.04	5.8
25 lb. of milk	1.025	4.75	1.075	5.25	1.125	6.0	1.225	6.75	1.30	7.25
30 lb. of milk	1.23	5.7	1.29	6.3	1.35	7.2	1.47	8.1	1.56	8.7
35 lb. of milk	1.435	6.65	1.505	7.35	1.575	8.40	1.715	9.45	1.820	10.15
40 lb. of milk	1.640	7.60	1.720	8.40	1.800	9.60	1.960	10.80	2.080	11.60

	5% milk		5.5% milk		6% milk		6.5% milk		7% milk	
	True Protein	Net Energy	True Protein	Net Energy	True Protein	Net Energy	True Protein	Net Energy	True Protein	Net Energy
1 lb. of milk	.055	.32	.058	.34	.061	.36	.064	.39	.068	.41
5 lb. of milk	.275	1.60	.290	1.70	.305	1.80	.320	1.95	.340	2.05
10 lb. of milk	.55	3.2	.58	3.4	.61	3.6	.64	3.9	.68	4.1
15 lb. of milk	.825	4.8	.87	5.1	.915	5.4	.96	5.85	1.02	6.15
20 lb. of milk	1.10	6.4	1.16	6.8	1.22	7.2	1.28	7.8	1.36	8.2
25 lb. of milk	1.375	8.00	1.450	8.50	1.525	9.00	1.60	9.75	1.70	10.35
30 lb. of milk	1.65	9.6	1.74	10.2	1.83	10.8	1.92	11.7	2.04	12.3
35 lb. of milk	1.925	11.20	2.03	11.9	2.135	12.60	2.24	13.65	2.380	14.35
40 lb. of milk	2.200	12.80	2.32	13.6	2.440	14.40	2.56	15.60	2.720	16.40

From Table 1 it will be seen that a 1,000 pound cow requires .5 pound of digestible true protein and 6 therms of net energy for maintenance alone. If the same cow is producing 20 pounds of 4 per cent milk she must be fed, in addition, according to Table 2, .98 pounds of digestible true protein and 5.4 therms of net energy, or a total in the daily ration of 1.48 pounds of digestible true protein and 11.4 therms of net energy. A cow of the same weight producing only 10 pounds of 4 per cent milk would need, in addition to the maintenance, .49 pounds of digestible true protein and 2.7 therms of net energy, or a total of .99 pounds of digestible true protein and 8.7 therms of net energy. If either of these cows should be fed much less, they will finally reduce the quantity of milk which they are giving, since they would not have sufficient food material from which to make the milk. The cow cannot change the quality of her milk to accommodate the food nutrients which she is receiving. If fed much more, some increase in milk might result, but a gain in flesh or fat would occur.

The following diagram shows what becomes of the feed eaten:



CLASSES OF FEED

All feeds given to dairy cows can be divided into two great classes:

1. Roughages (including roots)
2. Concentrates

The roughage consists of the hay, corn stover, straw and silage, in fact, all the coarse portions of the ration.

The concentrates have reference to the corn meal, oats, etc., in fact, all the grain and mill products.

THE ART OF FEEDING

The art of feeding was partly developed before and partly with the science of feeding. This art can be summarized in three general rules as follows:

1. Feed the grain mixture in proportion to the milk yield. The most general rule is to feed one pound of the grain per day for each three to four pounds of milk produced per day, according to the quality of the milk.
2. Feed all the roughage that the cow will eat up clean. Some of the roughage should be succulent in character.
3. Whenever the cow shows signs of becoming fat, reduce either the amount of roughage or grain, or even some of both, the one to be reduced to be determined by the cost.

Since the roughage is generally grown on the farm, the skillful feeder will try to have the cow eat as much of this as possible, as by so doing the expense of concentrates to be bought can be reduced. The art of feeding roughage can well be summarized by the following general rules:

1. Feed $2\frac{1}{2}$ to $3\frac{1}{2}$ pounds of silage for each 100 pounds of live weight of the cow. Most cows seem to prefer about 3 pounds.
2. Feed .5 to .8 pounds of hay, or its equivalent, in addition to silage, for each 100 pounds of live weight of the cow. Most cows seem to prefer about .6 pounds when being fed a grain mixture of one pound for each three pounds of milk produced. The quality of the roughage will have much to do with the amount consumed, hence some cows may eat one pound of hay for each 100 pounds of live weight, in addition to the silage.

3. A farmer not having silage, or any other succulent feed, will find that his cows will eat from 1.6 to 2 pounds of roughage for each 100 pounds of live weight.

These rules are simply useful guides for the beginner in the feeding of dairy cows. They are fairly accurate in so far as quantity of the food is concerned. When a feeder takes into consideration both quantity and quality of the food and of the milk, he passes from the art of feeding to that of balancing rations.

From Tables 1 and 2 of this bulletin, it is easy to calculate what an animal requires, and from Table 5 can be calculated the nutrients in the feeds, but in general, it is not practicable to calculate balanced rations for every cow in the herd for every week that she is giving milk. It is desirable to balance a ration for the average cow in the herd and feed each cow the grain mixture in proportion to her milk yield, permitting the individual cow to vary the amount of roughage which she eats in accordance with her appetite.

POINTS ON SELECTING CONCENTRATES

In determining the concentrates to use in a grain mixture, several things should be kept in mind. The following factors are especially worthy of being considered:

1. Palatability

A feed is said to be palatable when its flavor is pleasing. Certain feeds, like corn, are palatable, while certain feeds, like cottonseed meal, are unpalatable until the cow has been taught to eat them. Unpalatable feeds should be mixed with palatable feeds. There is some proof that the amount of digestive juices excreted depends upon the palatability of the feed.

2. Bulk

A grain mixture is said to have bulk when a definite weight takes up a relatively large space. To illustrate, 100 pounds of wheat bran will occupy much more space than 100 pounds of corn meal, and hence is said to be bulky or light. It is believed by dairymen that this bulk in itself enables the digestive juices to more completely penetrate the mass and hence may facilitate di-

gestion. At any rate, it is known that a dairy cow, to do well, must have the digestive tract well extended, and where heavy grain feeding is practiced some of the benefit of bulk ordinarily secured in the roughage can probably well come in the grain mixture. Unless the grain mixture is fed on the silage, or other roughage, it is well that it have bulk in itself.

3. Variety

In compounding a grain mixture so that it will have palatability and bulk and be properly balanced, generally three or four grains are used in the mixture. This is commonly spoken of as variety in the grain mixture. From recent investigations, it would seem well that care should be taken to see that grains of distinctly different species of plants should be used. This will help furnish the animal with needed ash ingredients and special forms of protein required by a cow in milk. It is not variety simply to feed several different named feeds all coming from the same plant, such as corn stover, corn and cob meal, corn bran, gluten, corn distillers' grains, etc.

4. Effect on Health

Each feed has its own specific effect upon the animal body. We do not yet have the specific effect of all feeds, but certain effects of particular feeds are well understood. To illustrate, cottonseed meal is known to be constipating in its effect, while linseed meal is known to have a laxative effect. Some of the roughages are laxative, such as silage, clover hay and alfalfa hay; some are constipating, such as timothy hay, oat straw and corn stover. When the roughages are constipating in their effect, a grain mixture of a laxative nature must be fed, if the dairy cow is to do her best. The bowels of a dairy cow should be in a laxative condition, if the cow is making her best production.

5. Cost

In successful farming, the business side is at least three-fifths. From the point of view of computing rations for dairy cows in order to produce milk, cost would not come in, but in actual farming it is more than half. Dairy men often believe that the cost price per ton is the most important consideration. It is important, but more important is the relative cost of net energy and digestible

true protein in feeds. The farmer should calculate the cost of 100 pounds of digestible true protein and 100 therms of energy in all the feeds available, and then make the cheapest mixture that satisfies all his requirements.

6. Roughages Used

Concentrates are used to balance the roughages fed, and hence the nature of the concentrates will depend upon the roughages fed. It is easy to divide roughages into three general groups.

Group 1 includes timothy hay, corn stover and corn silage. Any one, or any combination, of these will need a great deal of protein in the grain mixture.

Group 2 includes mixed clover and timothy hay, or any combination half leguminous and half non-leguminous. This group will require a grain mixture with a medium amount of protein.

Group 3 includes the legumes as the entire roughage. This group needs the smallest amount of protein in the grain mixture.

HELPS IN COMPOUNDING GRAIN MIXTURES

In many cases the exact yield and composition of the milk is not known. In such cases, generally the exact amount of roughage fed is not known, yet it is possible, by using the accompanying table to make a grain mixture that will practically balance the roughage.

By dividing the therms of net energy by the pounds of digestible true protein, we can secure the ratio of these two in a grain mixture. This is known as the ratio of digestible true protein to net energy, and is shown as follows: 1 to 4, meaning that for every pound of digestible true protein in a grain mixture there are 4 therms of net energy.

To make the table useful, note the following points:

1. Determine to which group the available roughage belongs.
2. Decide the amount of grain to be fed in proportion to milk yield.
3. Determine the average yield of milk of each cow in the herd, or for the average cow in the herd.
4. Determine the average test of the milk.

When the test of butter-fat is not known, the following table will be of help in making an estimate:

Herd all Jerseys or Guerneys or high grades.....	5.0%
Mixed herd with some Jersey or Guernsey animals..	4.5%
Common mixed herd and Ayrshires.....	4.0%
Herd all Holsteins.....	3.5%

Table 3.—The Ratio of Digestible True Protein to Net Energy for the Grain Mixture to Be Used With Different Roughages, Qualities and Quantities of Milk

Roughage	Per cent of fat in milk	When feeding one pound of grain for each four pounds of milk produced daily		When feeding one pound of grain for each three pounds of milk produced daily	
		With daily milk production per cow of		With daily milk production per cow of	
		15-25 lbs.	25-35 lbs.	15-25 lbs.	25-35 lbs.
		Ratio of digestible true protein to net energy 1 to	Ratio of digestible true protein to net energy 1 to	Ratio of digestible true protein to net energy 1 to	Ratio of digestible true protein to net energy 1 to
Group I Consisting of timothy hay, corn silage, corn stover, or when any two or three non-legumes make up the roughage	3%-4%	4.0	4.2	4.4	4.6
	4%-5%	4.4	4.6	4.8	5.0
	5%-6%	4.8	5.0	5.2	5.4
Group II When besides silage, at least half of the additional roughage is leguminous	3%-4%	5.0	5.2	5.4	5.6
	4%-5%	5.4	5.6	5.8	6.0
	5%-6%	5.8	6.0	6.2	6.4
Group III When all the roughage is leguminous	3%-4%	7.4	7.0	7.8	7.4
	4%-5%	7.6	7.2	8.0	7.6
	5%-6%	7.8	7.4	8.2	7.8

CONVENIENCE TABLE

To lessen the labor of computing, the decimal fractions have been generally omitted in the following table. It will be found sufficiently accurate, except where the real factors are known exactly, when Table 5 should be used. The columns "Cost of Protein" and "Net Energy" have been added for the convenience of comparing the relative cost of protein and net energy in different feeds.

Table 4.—Convenience Table for Computing Grain Mixtures.
(For Exact Composition Use Table 5, Page 21)

Ratio of digestible true protein to net energy		Digestible true protein and net energy in					Cost of true protein and net energy		
		25 Lbs.	50 Lbs.	100 Lbs.	200 Lbs.	300 Lbs.	Price 100 lbs.	Cost 100 lbs. Pro.	Cost 100 T. energy
1 to	By-products of milling								
		P	2.5	4.5	9.	18.	27.		
3.4	Buckwheat bran	E	7.5	15.	31.	61.	92.		
		P	5.	10.5	21.	42.	62.		
3.5	Buckwheat middlings	E	18.	36.	72.	144.	216.		
		P	1.5	3.	7.	13.	20.		
12.5	Hominy feed	E	20.5	41.	81.	163.	244.		
		P	2.5	5.	11.	21.	32.		
7.5	Rye bran	E	20.	39.5	79.	159.	228.		
		P	2.5	5.5	11.	22.	32.		
4.9	Wheat bran	E	13.	26.5	53.	106.	165.		
		P	3.5	7.	14.	28.	42.		
5.4	Wheat middlings—flour	E	19.	37.5	75.	150.	225.		
		P	3.	6.	12.	24.	36.		
4.9	Wheat middlings—standard	E	15.	29.5	59.	118.	177.		
	By-products of oil extraction								
		P	4.5	9.	18.	37.	55.		
4.5	Cocconut meal—low in fat	E	21.	42.	84.	167.	251.		
		P	9.	17.5	35.	71.	106.		
2.6	Cottonseed meal—choice	E	23.5	47.	93.	187.	280.		
		P	8.	16.	32.	64.	96.		
2.8	Cottonseed meal—prime	E	22.5	45.	90.	180.	270.		
		P	7.5	15.5	31.	62.	93.		
2.7	Linseed meal—new process	E	21.	42.5	85.	170.	255.		
		P	7.	14.	29.	57.	86.		
3.1	Linseed meal—old process	E	22.	44.5	89.	198.	267.		
		P	9.5	18.5	37.	75.	112.		
2.6	Soybean meal—fat extracted	E	25.	50.	100.	199.	300.		
	By-products of fermentation								
		P	5.	10.	20.	40.5	61.		
2.6	Brewers' grains, dried	E	13.5	26.5	53.	106.5	160.		
		P	1.	2.	4.	9.	13.		
3.3	Brewers' grains, wet	E	3.5	7.5	15.	29.	44.		
		P	4.5	9.	18.	36.	55.		
4.7	Distillers' grains dried from corn	E	21.	42.5	85.	170.	255.		
		P	3.	5.5	11.	22.	35.		
5.5	Distillers' grains dried from rye	E	14.	28.	56.	112.	168.		
		P	.5	1.5	3.	5.5	8.5		
7.8	Distillers' grains, wet	E	5.5	11.	22.	44.	66.		
		P	3.	6.	13.	25.	37.		
5.8	Malt sprouts	E	18.	36.5	73.	145.	218.5		
	By-products of starch manufacture								
		P	5.	10.	20.	40.	60.		
4.0	Gluten feed	E	20.	40.5	81.	161.	242.		
		P	7.	14.	28.	56.	84.		
3.0	Gluten meal	E	21.	42.	84.	168.	253.		

Table 4.—Convenience Table for Computing Grain Mixtures (Continued)

Ratio of digestible true protein to net energy			Digestible true protein and net energy in					Cost of true protein and net energy		
			25 Lbs.	50 Lbs.	100 Lbs.	200 Lbs.	300 Lbs.	Price 100 lbs.	Cost 100 lbs. Pro.	Cost 100 T. energy
1 to	<i>By-products of sugar manufacture</i>									
	Molasses, beet	P E	0 14.	0 28.5	0 57.	0 114.	0 171.			
	Molasses, corn or blackstrap	P E	0 14.	0 27.5	0 55.0	0 111.	0 166.			
108.4	Sugar beet pulp, dried	P E	.2 19.	.4 38.	.7 76.	1.5 152.	2.1 228.			
18.0	Sugar beet pulp, wet	P E	.1 2.	.3 4.5	.5 9.	1. 18.	1.5 27.			
	<i>By-products of slaughter house</i>									
1.0	Dried blood	P E	17. 17.	34.5 34.	69. 68.	137. 136.	206. 204.			
1.7	Tankage—over 60% protein	P E	14. 23.	28. 46.5	56. 93.	111. 186.	167. 279.			
	<i>Cereal grains</i>									
10.8	Barley	P E	2. 22.5	4. 45.	8. 90.	17. 180.	25. 270.			
8.3	Buckwheat	P E	2. 15.	3.5 30.	7. 60.	14. 119.	22. 179.			
12.7	Corn, dent	P E	1.5 22.	3.5 44.5	7. 89.	14. 178.	21. 267.			
12.2	Corn, flint	P E	2. 22.	3.5 44.	7. 88.	14. 175.	22. 263.			
13.3	Corn and cob meal	P E	1.5 19.	3. 38.	6. 76.	11. 152.	17. 227.			
13.8	Corn meal	P E	1.5 22.	3. 44.5	6.5 89.	13. 177.5	19. 266.			
7.8	Oats	P E	2. 16.5	4.5 34.	9. 68.	17.5 135.	26. 203.			
10.4	Rye	P E	2. 23.5	4.5 47.	9. 94.	18. 187.	27. 281.			
11.4	Wheat, all analyses	P E	2. 23.	4. 46.	8. 92.	16. 183.5	24. 275.			
	<i>Leguminous seeds</i>									
4.5	Bean, navy	P E	4. 18.5	8. 36.5	16. 73.	33. 147.	49. 220.			
4.7	Cowpea	P E	4. 20.	8.5 39.5	17. 79.	34. 159.	51. 239.			
4.7	Pea, field	P E	4. 19.5	8.5 39.5	17. 79.	33. 157.	50. 236.			
3.0	Soybean	P E	7. 20.5	13.5 40.5	27. 81.	55. 163.	82. 244.			

Table 4.—Convenience Table for Computing Grain Mixtures (Continued)

Ratio of digestible true protein to net energy			Digestible true protein and net energy in					Cost of true protein and net energy		
			1 Lb.	4 Lbs.	6 Lbs.	8 Lbs.	10 Lbs.	Price 100 lbs.	Cost 100 lbs. Pro.	Cost 100 T. energy
1 to	<i>Roughages</i>									
4.8	Alfalfa hay	P	.071	.284	.436	.568	.710			
		E	.342	1.369	2.054	2.738	3.423			
7.8	Red clover	P	.049	.196	.294	.392	.490			
		E	.387	1.547	2.321	3.094	3.868			
12.8	Mixed clover and timothy	P	.032	.128	.192	.256	.320			
		E	.411	1.643	2.464	3.286	4.107			
19.6	Timothy hay	P	.022	.088	.132	.176	.220			
		E	.430	1.721	2.581	3.442	4.302			
19.1	Corn stover	P	.016	.064	.096	.128	.160			
		E	.316	1.265	1.897	2.530	3.162			
			Digestible true protein and net energy in					Cost of protein and net energy		
			20 Lbs.	25 Lbs.	30 Lbs.	35 Lbs.	40 Lbs.	Price 100 lbs.	Cost 100 lbs. Pro.	Cost 100 T. energy
26.5	Corn silage	P	.120	.150	.180	.210	.240			
		E	3.180	3.978	4.770	5.565	6.360			

Let us assume that we have a cow weighing 1,000 pounds and giving 20 pounds of 4.5% milk. The only roughage available is in Group 1, and consists of timothy hay. From Table 3, it will be seen that a cow in Group 1, giving 20 pounds of 4.5% milk, and being fed grain, 1 pound for each 3 pounds of milk, would need a ratio of digestible true protein to net energy of 1 to 4.8. The question, then, is how to compute a grain mixture with this ratio. From the Convenience Table (No. 4) it will be seen that,

	Digestible true protein Lbs.	Net energy Therms
275 lbs. corn meal contains	17.5	244.0
150 lbs. cottonseed meal contains	52.5	139.
200 lbs. distiller' grains (dried) contains	36.	170.
100 lbs. gluten feed contains	20.	81.
725 lbs. total	126.0	645.0
1 pound contains	.173	.889

The ratio of digestible true protein to net energy is $645.0 \div 126.0 = 5.1$.

In order to narrow the ratio, as is necessary to do, it will be seen that this can be done by adding either 50 pounds of cottonseed meal or 50 pounds of linseed meal. By adding 50 pounds of cottonseed meal:

	Digestible true protein Lbs.	Net energy Therms
725 lbs. uncorrected total	126.0	645.
50 lbs. cottonseed meal adds.....	17.5	47.0
775 lbs. corrected total	143.5	692.
corrected total for 1 lb.	.185	.893

The ratio of digestible true protetin to net energy is $692.0 \div 143.5 = 4.8$.

By adding 50 lbs. of linseed meal (new process):

	Digestible true protein Lbs.	Net energy Therms
725 lbs. uncorrected total	126.0	645.
50 lbs. linseed meal adds	15.5	42.5
775 lbs. corrected total	141.5	687.5
corrected total for 1 lb.	.183	.887

The ratio of digestible true protetin to net energy is $687.5 \div 141.5 = 4.8$.

Either one of these two mixtures gives the ratio of digestible true protein to net energy that we are looking for. Since the roughage is timothy hay, the last grain mixture would be the better, since it is more laxative.

To illustrate how this would successfully work in practice, from Tables 1 and 2, it will be seen that the requirement for a 1,000 pound cow giving 20 pounds of 4.5% milk would be as follows:

	Digestible true protein	Net energy Therms
Maintenance	.5	6.
20 lbs. of 4.5% milk	1.04	5.8
Total requirements.....	1.54	11.8

From Table 3, it will be seen that if we were feeding grain, 1 pound for each 3 pounds of milk, approximately 6 pounds of grain would be needed. Six pounds of the above grain mixture would contain 1.10 pounds of protein and 5.32 therms of net energy. From the general rule for feeding roughage (Rule 3) it will be observed that when no silage is present from 1.6 to 2 pounds of hay per hundred weight should be fed.

	Digestible true protein Lbs.	Net energy Therms
16 lbs. of timothy hay would contain.....	.35	6.88
6 lbs. of grain.....	1.10	5.31
Total supplied	1.44	12.20

It will be seen that this is practically the requirement, as given above. There is a little excess of energy in the example, but it is as near as the feeds will analyze.

COST OF ABOVE RATION

The cost of a ration is something which must be figured on every farm. The following method will illustrate the way of determining it, assuming that we have but two prices; these must be considered as only illustrative:

Corn meal	\$1.60 per hundred pounds
Cottonseed meal	1.80 per hundred pounds
Dried distillers' grains (corn)....	1.60 per hundred pounds
Gluten feed	1.60 per hundred pounds
Linseed meal (N. P.).....	1.80 per hundred pounds

The following table will show the cost of 100 pounds of digestible true protetin and 100 therms of net energy in the above ration, figured in accordance with Convenience Table No. 4:

Cost of Digestible True Protein and Net Energy in Above Feeds

Feeds	Digestible true protein and net energy	Price per ton	Price per 100 lbs.	Cost of 100 lbs. digestible true protein	Cost of 100 therms of net energy
Corn meal.....	P 6.5 E 89	\$32 00	\$1 60	\$24 62	\$1 80
Cottonseed meal.....	P 35 E 93	36 00	1 80	5 14	1 94
Dried distillers' grains (corn).....	P 18 E 85	32 00	1 60	8 89	1 88
Gluten feed	P 20 E 81	32 00	1 60	8 00	1 98
Linseed meal (N. P.)	P 31 E 85	36 00	1 80	5 81	2 12

The following explanation illustrates how the cost of digestible true protein and net energy were determined:

Dividing the cost of 100 pounds of corn meal (\$1.60) by the 6.5 pounds of digestible true protein which it contains gives 24.62 cents, the cost of one pound of digestible true protein; multiplying this by 100 gives \$24.62, the cost of 100 pounds of digestible true protein. In like manner, dividing the \$1.60, by the 89 therms of net energy, which 100 pounds of corn meal contains, gives 1.8 cents, the cost of one therm of net energy; multiplying this by 100 gives \$1.80, the cost of 100 therms of net energy.

This is the method to use in figuring the cost of digestible true protein and net energy in each feed.

In looking at the above table it will be observed that, at the prices assumed, the relative cost of net energy does not vary as does the relative cost of digestible true protein.

More emphasis should be put upon the cost of 100 Therms of net energy than upon the cost of the digestible true protein. The home grown feeds, especially corn, are usually rich in net energy. The ration, however, must contain sufficient protein to properly nourish the animal, and in buying rich protein feeds the cost of the protein should always be calculated, and the cheapest ration will usually contain the grain which furnishes digestible true protein at the cheapest rate.

Actual Cost of Above Ration

275 pounds corn meal cost.....	\$ 4.40
150 pounds cottonseed meal cost.....	2.70
200 pounds distillers' grains, dried, cost.....	3.20
100 pounds gluten feed cost.....	1.60
50 pounds linseed meal cost.....	.90
775 pounds cost	\$12.80
100 pounds would cost	\$ 1.65
100 pounds digestible true protetin would cost.....	9.02
100 therms of net energy would cost.....	1.89

RATIONS ON PASTURE

Experiments show that grain should be fed on good pasture to cows that give a large flow of milk. If cows are to do well on poor pasture they must be fed in addition to the pasture grass. It is impossible to make a grain mixture that will balance pasture grass throughout the season. In the early spring pasture grass contains much more protein than it contains later. Furthermore, droughts, etc., affect the growth of the different grasses, hence different grains are necessary to properly balance a ration at different times. Undoubtedly corn meal, wheat bran, oats, cottonseed meal, oil meal, distillers' grains and gluten feed are some of the best feeds to be used on pasture. In the early spring the mixture can be made up with a relatively small amount of the higher protein feeds, and if the flow of milk does not seem to keep up it will pay to add those containing more protein; and even the amount of grain fed can well be increased. From 3 to 10 pounds of grain daily are the limits most commonly found in feeding grain to cows on pasture. Whenever pastures are insufficient, especially late in the summer, silage is a most excellent feed for dairy cows. Since silage is deficient in protein, care must be taken to see that the grain mixture is rich in this ingredient.

A FEW SPECIMEN GRAIN MIXTURES

The following specimen grain mixtures are given merely as suggestions, and not because it is believed that they are the cheapest or in any way the best. Grain mixtures must be worked out on every farm and under the conditions existing there.

No. 1.

	Protein	Therms energy
100lbs. buckwheat middlings ...	21.	72.
100lbs. wheat bran..	11.	53.
100lbs. coconut meal	18.	84.
200lbs. cottonseed meal	35.	93.
200lbs. dried distillers' grains (corn)	36.	170.
700lbs. contains	121.	472.
1lb. contains	.173	.674
Ratio of digestible true protein to net energy, 1 to 4.		

No. 3.

250lbs. corn meal....	16.	222.
50lbs. cottonseed meal	17.5	47.
50lbs. dried brewers' grains	10.	26.5
100lbs. gluten feed..	20.	81.
100lbs. linseed meal (O. P.).....	29.	89.
100lbs. wheat bran...	11.	53.
650lbs. contains	103.5	518.5
1lb. contains	.159	.798
Ratio of digestible true protein to net energy, 1 to 5.		

No. 5.

475lbs. corn and cob meal	26.5	360.
100lbs. cottonseed meal	35.	93.
100lbs. dried distillers' grains (corn)	18.	85.
100lbs. gluten feed..	20.	81.
775lbs. contains	99.5	619.
1lb. contains	.128	.787
Ratio of digestible true protein to net energy, 1 to 6.2.		

No. 7.

700lbs. corn meal...	45.5	623.
50lbs. cottonseed meal	17.5	47.
100lbs. gluten feed.	20.0	81.
50lbs. linseed meal (O. P.).....	14.	44.5
400lbs. wheat bran..	44.	212.
1300lbs. contains	141.	1007.5
1lb. contains	.109	.775
Ratio of digestible true protein to net energy, 1 to 7.2.		

No. 2.

	Protein	Therms energy
50lbs. corn meal....	3.	44.5
150lbs. cottonseed meal	52.5	140.
100lbs. dried distillers' grains (corn)	18.	85.
100lbs. gluten feed..	20.	81.
100lbs. hominy	7.	81.
100lbs. Linseed meal (O. P.).....	29.	89.
100lbs. oats	9.	68.
700lbs. contains	128.5	589.0
1lb. contains	.182	.841
Ratio of digestible true protein to net energy, 1 to 4.6.		

No. 4.

350lbs. corn and cob meal	20.	266.
100lbs. cottonseed meal	35.	93.
100lbs. dried distillers' grains (corn)	18.	85.
100lbs. gluten feed..	20.	81.
650lbs. contains	93.	525.
1lb. contains	.143	.808
Ratio of digestible true protein to net energy, 1 to 5.6.		

No. 6.

350lbs. corn meal...	20.	266.
300lbs. oats	26.	203.
100lbs. linseed meal (O. P.).....	29.	89.
300lbs. wheat bran..	32.	165.
1000lbs. contains	107.	723.
1lb. contains	.107	.723
Ratio of digestible true protein to net energy, 1 to 6.8.		

No. 8.

425lbs. corn and cob meal	23.5	323.
50lbs. cottonseed meal	17.5	47.
100lbs. dried distillers' grains (corn)	18.	85.
100lbs. wheat bran...	11.	53.
100lbs. dried beet pulp	.7	76.
775lbs. contains	70.7	584.
1lb. contains	.0912	.753
Ratio of digestible true protein to net energy, 1 to 8.2.		

A FEW GENERAL CONSIDERATIONS

In selecting feeds many characteristics of them should be known. The following are a few that it is well to bear in mind:

1. Bulky feeds

Brewers' grains
Corn and cob meal
Distillers' grains (corn and rye)
Gluten feed (slightly)
Malt sprouts
Oats
Rye bran
Sugar beet pulp
Wheat bran
All roughages

2. Constipating feeds

All straws, and to a large extent all hays other than leguminous hays
Corn fodder
Corn stover
Timothy hay
Cottonseed meal

3. Laxative feeds

Linseed meal (old process more than new process)
In fact, all leguminous seeds and oil seeds
Wheat bran
All silage (frosted silage not as much as non-frosted)
Roots, tubers and fruits
Hay from legumes
All fresh green roughages

4. Palatable feeds

All hays and fodders from legumes, if properly cured
Fresh green roughages, both cereals and legumes at the proper stage
Silage
Roots, tubers and fruits
Oats
Corn

Hominy feed
Wheat
Wheat bran
Wheat middlings
Molasses
Sugar beet pulp
Linseed meal

5. Unpalatable feeds

Buckwheat hulls
Brewers' grains
By-products of oil extraction generally
Cottonseed meal
Distillers' grains
Gluten feed

All dried roughages classed as hay and fodder from cereals,
unless care has been taken to harvest them

6. Proprietary feeds

In Pennsylvania the law guards the honesty of all concentrated commercial feeding stuffs sold. The report upon them is published annually.* Proprietary feeds save much labor in mixing, and often for the farmer who can buy only in small amounts they are relatively cheap. In general, for the farmer who buys in bulk they are relatively expensive, and many of them contain weed seeds and other waste materials that the farmer does not care to buy. Furthermore, a farmer cannot accurately balance a ration because the makers do not publish digestible nutrients.

Condimental and Tonic Stock Feeds

Since it is well known that spiced foods and condimentals in general increase the secretion of the digestive juices, especially in the mouth, it has long been held that they were valuable for dairy cattle. While they may do some animals a little good, they are not worth the price for which they sell; sick animals need something more, and condiments do not increase the milk flow sufficiently to pay for themselves. If an animal needs salt, charcoal, sulphur and ash, the farmer should mix his own rather than buy.

* State Department of Agriculture, Harrisburg.

Table 5.—Average Dry Matter, Digestible Crude Protein,
Digestible True Protein, and Net Energy Values
Per 100 Pounds for Ruminants

	Dry matter	Digestible		Net energy value
		Crude protein	True protein	
DRIED ROUGHAGE				
<i>Hay and fodder from cereals</i>				
	Lbs.	Lbs.	Lbs.	Therms
Brome grass, smooth.....	91.5	5.0	3.5	40.83
Corn fodder (ears included, medium dry) ..	81.7	3.0	2.3	43.94
Corn stover (ears removed, medium dry)...	81.0	2.1	1.6	31.62
Millet, Hungarian	85.7	5.0	3.9	46.96
Mixed timothy and clover.....	87.8	5.3	3.6	40.85
Oat hay	88.0	4.5	3.9	32.25
Orchard grass	88.4	4.7	3.3	44.93
Red top	90.2	4.6	3.9	51.22
Timothy, all analyses	88.4	3.0	2.2	43.02
Timothy, before bloom	92.8	4.7	2.9	43.52
Timothy, early to full bloom.....	87.2	3.6	2.5	47.40
Timothy, late bloom to early seed.....	85.1	2.4	1.8	37.54
Timothy, nearly ripe	87.5	2.2	1.8	38.59
<i>Hay and fodder from legumes</i>				
Alfalfa, all analyses	91.4	10.6	7.1	34.23
Alfalfa, before bloom	93.8	15.4	10.3	36.23
Alfalfa, in bloom	92.5	10.5	6.7	32.33
Alfalfa, in seed	89.6	8.5	6.2	32.23
Clover, alsike	87.7	7.9	5.3	34.42
Clover, crimson	89.4	9.7	6.9	36.21
Clover, red, all analyses	87.1	7.6	4.9	38.68
Clover, red, before bloom	89.6	11.6	5.4	42.17
Clover, red, in bloom	86.1	8.1	5.3	39.12
Clover, red, after bloom	77.9	6.8	4.5	34.51
Clover, sweet, white	91.4	10.9	6.7	38.98
Cowpeas, all analyses	90.3	13.1	9.2	37.59
Cowpeas, before bloom	92.2	17.8	12.8	33.54
Cowpeas, in bloom to early pod.....	89.4	12.6	9.5	39.11
Soybeans	91.4	11.7	8.8	44.03
<i>Straws</i>				
Barley	85.8	0.9	0.6	36.61
Buckwheat	90.1	4.2	3.2	4.55
Oat	88.5	1.0	0.8	34.81
Rye	92.9	0.7	0.5	17.59
Wheat	91.6	0.7	0.3	7.22
FRESH GREEN ROUGHAGE				
<i>Green cereals, etc.</i>				
Barley fodder	23.2	2.3	2.0	14.08
Blue grass, Kentucky, before heading	23.8	3.7	2.8	14.82
Blue grass, Kentucky, headed out.....	36.4	2.8	2.2	17.77
Blue grass, Kentucky, after bloom	43.6	1.9	1.6	21.01
Buckwheat, Japanese	36.6	2.2	1.5	17.78
Cabbage	8.9	1.9	1.3	8.87
Cabbage, waste outer leaves.....	14.1	1.7	1.1	7.05

Table 5.—Average Dry Matter, Digestible Crude Protein, Digestible True Protein, and Net Energy Values Per 100 Pounds for Ruminants—Continued

	Dry matter	Digestible		Net energy value
		Crude protein	True protein	
	Lbs.	Lbs.	Lbs.	Therms
Corn fodder, dent, all analyses.....	23.1	1.0	0.8	14.60
Corn fodder, dent, in tassel.....	14.9	1.1	0.8	9.52
Corn fodder, dent, in milk.....	19.9	1.0	0.8	13.64
Corn fodder, dent, dough to glazing.....	25.1	1.3	1.0	17.35
Corn fodder, dent, kernels glazed.....	26.2	1.1	0.8	16.74
Corn fodder, dent, kernels ripe.....	34.8	1.5	1.1	22.48
Corn fodder, flint, all analyses.....	20.7	1.0	0.8	13.53
Corn fodder, flint, in tassel.....	10.6	0.9	0.7	6.89
Corn fodder, flint, in milk.....	15.0	0.9	0.7	10.39
Corn fodder, flint, kernels glazed.....	21.0	1.0	0.8	13.49
Corn fodder, flint, kernels ripe.....	27.9	1.2	0.9	17.84
Corn fodder, sweet, before milk stage.....	10.0	0.8	0.6	7.82
Corn fodder, sweet, roasting ears or later.....	20.3	1.2	0.9	13.38
Corn fodder, sweet, ears removed.....	21.5	1.0	0.8	14.26
Millet, Hungarian.....	27.6	1.9	1.1	17.24
Oat fodder.....	26.1	2.3	2.0	14.06
Orchard grass.....	29.2	1.7	1.1	15.81
Rape.....	16.7	2.6	1.7	13.07
Rye fodder.....	21.3	2.1	1.4	15.99
Sweet sorghum fodder.....	24.9	0.7	0.4	15.37
Timothy, before bloom.....	24.2	1.8	1.1	18.36
Timothy, in bloom.....	32.1	1.3	0.8	18.89
Timothy, in seed.....	46.4	1.5	1.0	26.36
Wheat fodder.....	27.4	2.8	1.9	18.75
<i>Green legumes</i>				
Alfalfa, before bloom.....	19.9	3.5	1.9	9.20
Alfalfa, in bloom.....	25.9	3.3	1.8	11.50
Alfalfa, after bloom.....	29.8	2.1	1.3	11.10
Clover, alsike.....	24.3	2.7	1.5	14.56
Clover, crimson.....	17.4	2.3	1.6	10.83
Clover, red, all analyses.....	26.2	2.7	1.7	15.87
Clover, red, in bloom.....	27.5	2.7	1.8	16.74
Clover, red, rowen.....	34.4	3.3	2.2	17.30
Cowpeas.....	16.3	2.3	1.7	10.42
Peas, Canada field.....	16.6	2.9	2.1	9.78
Soybeans, all analyses.....	23.6	3.2	2.4	12.53
Soybeans, in bloom.....	20.8	3.0	2.3	10.44
Soybeans, in seed.....	24.2	3.1	2.5	12.70
Vetch, hairy.....	18.1	3.5	2.4	11.95
<i>SILAGE</i>				
Corn, well-matured, recent analyses.....	26.3	1.1	0.6	15.90
Corn, immature.....	21.0	1.0	0.4	11.96
Corn, from frosted ears.....	25.3	1.2	0.6	14.27
Corn, from field-cured stover.....	19.6	0.5	0.3	8.98
Clover.....	27.8	1.3	0.8	7.26
Cowpeas.....	22.0	1.8	1.1	11.05
Soybeans.....	27.1	2.6	1.5	11.59
Sugar beet pulp.....	10.0	0.8	0.5	9.32

Table 5.—Average Dry Matter, Digestible Crude Protein, Digestible True Protein, and Net Energy Values Per 100 Pounds for Ruminants—Continued

	Dry matter	Digestible		Net energy value
		Crude protein	True protein	
	Lbs.	Lbs.	Lbs.	Therms
<i>ROOTS, TUBERS AND FRUITS</i>				
Apple.....	18.2	0.4	0.1	15.92
Beet, common.....	13.0	0.9	0.1	7.84
Beet, sugar.....	16.4	1.2	0.4	11.20
Carrot.....	11.7	0.9	0.5	9.21
Mangels.....	9.4	0.8	0.1	5.68
Potatoes.....	21.2	1.1	0.1	18.27
Pumpkin, field.....	8.3	1.1	0.6	6.05
Rutabaga.....	10.9	1.0	0.3	8.46
Turnip.....	9.5	1.0	0.4	6.16
<i>GRAINS</i>				
<i>Cereal grains</i>				
Barley.....	90.7	9.0	8.3	89.94
Buckwheat.....	87.9	8.1	7.2	59.73
Corn, common.....	89.5	7.5	7.0	89.16
Corn, dent.....	87.8	7.7	7.2	87.50
Corn, flint.....	89.6	6.1	5.7	75.80
Corn and cob meal.....	88.7	6.9	6.4	88.75
Corn meal.....	90.8	9.7	8.7	67.56
Oats.....	92.1	12.8	11.5	86.20
Oat meal.....	90.6	9.9	9.0	93.71
Rye.....	89.8	9.2	8.1	91.82
Wheat, all analyses.....	89.1	8.7	7.7	91.66
Wheat, winter.....	89.9	9.2	8.1	91.41
Wheat, spring.....				
<i>Leguminous seeds</i>				
Bean, navy.....	86.6	18.8	16.4	73.29
Cowpea.....	88.4	19.4	16.9	79.46
Pea, field.....	90.8	19.0	16.6	78.72
Pea meal.....	89.1	19.8	17.2	77.62
Peanut with hull.....	93.5	19.4	16.9	83.15
Peanut kernel.....	94.0	24.1	22.2	109.04
Soybean.....	90.1	30.7	27.3	81.29
<i>Oil seeds</i>				
Cotton seed.....	90.6	13.3	11.9	78.33
Flax seed.....	90.8	20.6	19.2	83.17
Sunflower seed.....	95.5	23.3	20.2	95.77
Sunflower seed with hulls.....	93.1	13.5	11.7	92.49
<i>DAIRY PRODUCTS</i>				
Buttermilk.....	9.4	3.4	3.4	13.32
Cow's milk.....	13.6	3.3	3.3	29.01
Skimmilk—centrifugal.....	9.9	3.6	3.6	14.31
Skimmilk—gravity.....	9.6	3.1	3.1	15.43
Skimmilk—dried.....	91.7	34.4	34.4	103.91
Whey.....	6.6	0.8	0.8	10.39
<i>BY-PRODUCTS</i>				
<i>Fermentation industries</i>				
Brewers' grains, dried.....	92.5	21.5	20.2	53.38
Brewers' grains, dried, below 25% protein..	91.8	18.7	17.5	50.93

Table 5.—Average Dry Matter, Digestible Crude Protein, Digestible True Protein, and Net Energy Values Per 100 Pounds for Ruminants—Continued

	Dry matter	Digestible		Net energy value
		Crude protein	True protein	
	Lbs.	Lbs.	Lbs.	Therms
Brewers' grains, wet	24.1	4.6	4.4	14.53
Distillers' grains, dried, from corn	93.4	22.4	18.3	85.08
Distillers' grains, dried, from rye	92.8	13.6	11.1	56.01
Distillers' grains, wet	22.6	3.3	2.8	22.05
Malt	94.2	15.8	11.8	87.82
Malt sprouts	92.4	20.3	12.5	72.72
<i>Milling</i>				
Buckwheat bran	88.8	10.5	9.1	30.59
Buckwheat hulls	89.7	0.4	?	-7.69
Buckwheat middlings	88.0	24.6	20.8	72.19
Hominy feed	89.9	7.0	6.5	81.31
Rye bran	88.6	12.2	10.5	79.35
Wheat bran	89.9	12.5	10.8	53.00
Wheat middlings, flour	89.3	15.7	14.0	75.02
Wheat middlings, standard	89.6	13.4	12.0	59.10
<i>Oil extraction</i>				
Cocanut meal, low in fat	90.4	18.8	18.3	83.49
Cocanut meal, high in fat	92.3	18.4	18.0	100.31
Cottonseed hulls	90.3	0.3	?	9.92
Cottonseed meal, choice	92.5	37.0	35.4	93.46
Cottonseed meal, prime	92.2	33.4	32.0	90.00
Germ oil meal, corn	91.1	16.5	14.3	83.88
Linseed meal, new process	90.4	31.7	30.9	85.12
Linseed meal, old process	90.9	30.2	28.5	88.91
Palmnut cake	89.6	12.4	12.0	94.18
Peanut cake from hulled nuts	89.3	42.8	41.4	93.55
Peanut cake, hulls included	94.4	20.2	19.5	42.57
Soybean meal, fat extracted	88.2	38.1	37.3	99.65
Sunflower seed cake	90.0	32.0	29.1	88.87
<i>Starch manufacture</i>				
Gluten feed	91.3	21.6	20.1	80.72
Gluten meal	90.9	30.2	28.1	84.15
Starch feed, dry	90.7	11.2	9.2	77.46
Starch feed, wet	33.4	4.1	3.7	30.45
<i>Sugar manufacture</i>				
Molasses, beet	74.7	1.1	0.0	57.10
Molasses, cane or black strap	74.2	1.0	0.0	55.38
Molasses beet pulp	92.4	5.9	3.5	76.28
Sugar beet pulp, dried	91.8	4.6	0.7	75.87
Sugar beet pulp, ensiled	10.0	0.8	0.5	9.32
Sugar beet pulp, wet	9.3	0.5	0.5	8.99
<i>Packing house</i>				
Dried blood	90.3	69.1	68.6	68.12
Tankage				
Over 60% protein	92.6	58.7	55.6	93.04
55-60% protein	92.5	54.0	51.1	83.58
45-55% protein	92.5	48.1	45.5	72.96
Below 45% protein	93.5	37.6	35.6	54.16

ENERGY VALUES OF RED-CLOVER HAY AND MAIZE MEAL

By HENRY PRENTISS ARMSBY, *Director*, J. AUGUST FRIES, *Assistant Director*, and WINFRED WAITE BRAMAN, *Associate, Institute of Animal Nutrition of The Pennsylvania State College*

COOPERATIVE INVESTIGATIONS BETWEEN THE BUREAU OF ANIMAL INDUSTRY OF THE UNITED STATES DEPARTMENT OF AGRICULTURE AND THE INSTITUTE OF ANIMAL NUTRITION OF THE PENNSYLVANIA STATE COLLEGE

INTRODUCTION

The results of determinations at this institute of the net energy values for cattle of 10 different feeding stuffs or mixtures were reported by Armsby and Fries in a previous paper.¹ Attention was there called to the discordant results obtained for red-clover hay and for maize meal, and certain of them were tentatively rejected, for reasons stated, in making up the final averages. The present experiments were undertaken in order to obtain additional data concerning the energy values of these feeding stuffs. They were conducted in 1915 along the lines of the previous experiments just referred to.

GENERAL DESCRIPTION OF EXPERIMENTS

The general plan of the experiments was to feed five different rations. The first two consisted of two different amounts of red-clover hay alone, one a submaintenance ration, and the other a heavy ration. The remaining rations contained different amounts of a mixture of one-third clover hay and two-thirds maize meal, one amount being much below maintenance, one approximately maintenance, and one a heavy ration. Ten gm. of salt were added to each day's ration.

The animal used was a pure-bred Shorthorn steer, 2 years old, weighing at the beginning of the experiments a little over 500 kgm.

As in previous experiments, each feeding period covered 21 days, the first 11 being preliminary and the last 10 the digestion period proper. Table I gives the dates and the rations for the several periods and also the live weights of the animals.

¹ Armsby, H. P., and Fries, J. A. Net energy values of feeding stuffs for cattle. *In Jour. Agr. Research*, v. 3, no. 6, p. 435-491. 1915.

TABLE I.—Duration of experiments in 1915, rations fed, and live weight of the animals

Period No.	Preliminary period.	Digestion period.	Ration.		Live weight of steer.
			Clover hay.	Maize meal.	
			Gm.	Gm.	Kgm.
I.....	Jan. 3-13.....	Jan. 14-23.....	7,000	.....	513.5
II.....	Jan. 24-Feb. 3.....	Feb. 4-13.....	4,500	.....	497.2
III.....	Feb. 21-Mar. 3.....	Mar. 4-13.....	1,500	3,000	489.5
IV.....	Mar. 21-31.....	Apr. 1-10.....	2,500	5,000	513.5
V.....	Apr. 11-21.....	Apr. 22-May 1.....	1,000	2,000	491.2

The hay used was grown on the college farm and cut when in full bloom. It graded as "good hay." It was fed cut in lengths of 5 to 10 cm. The maize meal was ground from No. 2 yellow corn.

EXPERIMENTAL METHODS

The experimental and analytical methods in these experiments were the same as those previously given in detail,¹ with the exception of the determinations of carbon and hydrogen. The total carbon in the urines was determined directly by combustion of the liquid urine by a method worked out in this laboratory² and that of the feed and feces by combustion in a bomb calorimeter as described by Fries.³ The organic hydrogen was not determined, as it has been found that the error resulting from omitting it entirely from the computation is very small.

Table II shows the average composition of the dry matter of the feeding stuffs used.

TABLE II.—Composition of the dry matter of the feeding stuffs

Feeding stuff and period No.	Ash.	Protein.	Non-protein.	Crude fiber.	Nitrogen-free extract.	Ether extract.	Heat of combustion per kilogram.
Clover hay:	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	Calories.
I and II.....	5.81	8.26	1.11	34.34	48.54	1.95	4,367
III.....	6.20	9.49	1.25	31.40	49.33	2.34	4,403
IV and V.....	5.79	9.94	1.03	30.56	50.14	2.55	4,407
Average.....	5.93	9.23	1.13	32.10	49.34	2.28	4,393
Maize meal:							
III.....	1.44	9.74	.35	2.04	82.13	4.30	4,515
IV and V.....	1.37	9.82	.20	2.04	82.21	4.36	4,496
Average.....	1.41	9.78	.28	2.04	82.17	4.33	4,505

¹ Armsby, H. P., and Fries, J. A. The influence of type and of age upon the utilization of feed by cattle. U. S. Dept. Agr. Bur. Anim. Indus. Bul. 128, p. 203. 1911.

² Braman, W. W. A study in drying urine for chemical analysis. In Jour. Biol. Chem., v. 19, no. 1, p. 105-113. 1914.

³ Fries, J. A. The determination of carbon by means of the bomb calorimeter. In Jour. Amer. Chem. Soc., v. 31, no. 2, p. 272-278, 1 fig. 1909.

PERCENTAGE DIGESTIBILITY OF RATIONS

From the daily records of feed and excreta and their chemical composition the percentage digestibility of the several rations has been computed in the usual manner, with the results shown in Table III.

It was assumed that in the mixed rations the hay had the percentage digestibility shown by the average of the periods when hay was fed alone, and the percentage digestibility of the maize meal in Periods III, IV, and V has also been computed, with the results shown in the last three columns of the table.

TABLE III.—Digestibility of the rations

Constituent.	Percentage digestibility of rations.								
	Clover hay.		Clover hay and maize meal.			Average percentage digestibility of clover hay.	Computed percentage digestibility of maize meal.		
	Period I.	Period II.	Period III.	Period IV.	Period V.		Periods I and II.	Period III.	Period IV.
Dry matter.....	55.88	59.26	78.78	73.22	79.20	57.23	89.78	81.54	90.63
Ash.....	28.57	31.62	41.94	27.22	27.94	29.78	68.72	21.54	23.75
Organic matter.....	57.56	60.97	79.94	74.58	80.72	58.92	90.15	82.37	91.55
Protein.....	35.29	41.24	62.44	55.86	63.00	37.66	74.74	65.46	76.34
Crude fiber.....	50.23	53.19	54.22	47.54	46.55	51.41	76.27	17.42	8.68
Nitrogen-free extract.....	66.24	69.76	87.19	82.04	89.13	67.64	93.19	86.61	95.95
Ether extract.....	49.14	54.29	78.10	76.30	81.49	51.19	85.52	83.96	90.68
Total nitrogen.....	42.87	46.33	60.82	53.85	62.01	44.25	69.68	59.21	71.77
Carbon.....	54.10	57.50	77.85	72.41	78.32	55.46	89.32	81.25	90.23
Energy.....	53.80	57.20	77.28	71.87	77.65	55.15	88.29	80.40	89.12

METABOLIZABLE ENERGY

The difference between the chemical energy of the feed and that lost in the excreta shows how much of the former is capable of transformation in the animal body. This has been called metabolizable energy.

Computed in the same manner as in the earlier paper, the losses of chemical energy per kilogram of dry matter consumed and the metabolizable energy remaining were as shown in Table IV, which includes also the percentage distribution of the feed energy between the various excreta on the one hand and the metabolizable energy on the other.

The average results for the metabolizable energy per kilogram of dry matter and per kilogram of digestible organic matter are brought together for convenience in Table V.

TABLE IV.—Losses of energy and their percentage distribution

Feed and period No.	Dry matter eaten per head and per day.		Energy per kilogram of dry matter.					Metabolizable energy.	Metabolizable energy per kilogram of digestible organic matter.	Percentage losses.			Percentage metabolizable.
			Total.	Losses.			In feces.			In urine.	In methane.		
	Coarse feed.	Concentrate.		In feces.	In urine.	In methane.							
Clover hay:	Gm.	Gm.	Cal.	Cal.	Cal.	Cal.	Cal.	Cal.					
I.....	5,952	0	4,367	2,018	153	287	1,909	3,522	46.20	3.51	6.57	43.72	
II.....	3,942	0	4,367	1,869	172	304	2,022	3,522	42.80	3.93	6.96	46.31	
True average.....			4,367	1,958	161	294	1,954	3,522	44.85	3.68	6.72	44.75	
Clover hay and maize meal:													
III.....	1,328	2,602	4,477	1,017	173	413	2,874	3,708	22.72	3.86	9.23	64.19	
IV.....	2,272	4,363	4,465	1,256	136	340	2,733	3,733	28.13	3.05	7.61	61.21	
V.....	909	1,748	4,465	998	192	495	2,780	3,546	22.35	4.30	11.09	62.26	
True average.....			4,469	1,133	159	393	2,764	3,705	25.26	3.55	8.79	62.30	
Maize meal computed:													
III.....	1,328	2,602	4,515	529	179	473	3,334	3,753	11.71	3.96	10.48	73.85	
IV.....	2,272	4,363	4,496	881	133	363	3,129	3,851	19.60	3.73	8.07	69.60	
V.....	909	1,748	4,496	489	208	599	3,200	3,543	10.88	4.63	13.32	71.17	
True average.....			4,501	697	157	443	3,204	3,755	15.49	3.40	9.85	71.18	

TABLE V.—Average losses of chemical energy and metabolizable energy

Feed and period No.	Gross energy per kilogram of dry matter.	Losses of chemical energy per kilogram of dry matter.	Metabolizable energy.	
			Per kilogram of dry matter.	Per kilogram of digestible organic matter.
Clover hay:	Calories.	Calories.	Calories.	Calories.
I.....	4,367	2,458	1,909	3,522
II.....	4,367	2,345	2,022	3,522
True average.....	4,367	2,413	1,954	3,522
Maize meal computed:				
III.....	4,515	1,181	3,334	3,753
IV.....	4,496	1,367	3,129	3,851
V.....	4,496	1,296	3,200	3,543
True average.....	4,501	1,297	3,204	3,755
Clover hay and maize meal:				
III.....	4,477	1,603	2,874	3,708
IV.....	4,405	1,732	2,733	3,773
V.....	4,465	1,685	2,780	3,546
True average.....	4,469	1,685	2,784	3,705

A comparison of the metabolizable energy per kilogram of digested organic matter as given in Table IV with the previous results shows a very close agreement, the figures being for clover hay 3.52 therms as compared with 3.49 therms, and that for maize meal 3.76 therms as compared with 3.80 therms.

INFLUENCE OF QUANTITY OF FEED CONSUMED ON LOSSES OF CHEMICAL ENERGY

A study of the percentage losses of chemical energy substantially confirms the earlier results regarding the influence of the quantity of feed upon these losses. If Periods I and II, in which a large and a much smaller hay ration were fed under similar conditions, are compared, it is seen that with the smaller ration the losses in the urine and in the methane were decidedly greater and the loss in the feces less than with the larger ration.

Periods III, IV, and V are similarly comparable, the rations of hay and maize meal being fed under the same conditions but in varying quantities. Here, as in the periods when hay alone was fed, the lightest ration shows the greatest loss in urine and methane and the least in the feces, while with the heaviest ration the reverse was true. The losses computed for the maize meal alone show differences in the same direction.

As regards variation in the percentage of total energy which was metabolizable there were slight differences. In the case of both the hay rations and the mixed rations the largest feed gave the smallest percentage, but with the mixed ration the smallest feed did not give the largest percentage. As in the experiments previously reported, the quantity of feed failed to show any definite effect upon the percentage of energy metabolized.

METHANE PRODUCTION

The relation of the methane to the digestible carbohydrates has been found to be fairly constant, so that an average figure may be used to estimate the combustible gases in the absence of the costly apparatus necessary for their actual determination.

Table VI gives this relation as actually found in these experiments.

TABLE VI.—Quantity of methane per 100 gm. of digestible carbohydrates

Feed and period No.	Carbohydrates.	Methane.	Methane per 100 gm. of digestible carbohydrates.	Average.
Clover hay:	Gm.	Gm.	Gm.	Gm.
I.....	2,940.6	127.9	4.35	4.36
II.....	2,054.4	89.8	4.37	
Hay and maize meal:				
III.....	2,689.2	121.7	4.53	4.63
IV.....	4,249.3	169.1	3.98	
V.....	1,832.4	98.6	5.38	

If these figures are compared with those of the previous experiments it is seen that while Periods I and II agree very closely, the average is somewhat lower than the earlier average for clover hay, 4.6 gm. The results from Periods III, IV, and V vary rather widely, although their average, 4.63 gm., is only a little lower than the average of the previous experiments, 4.8 gm.

HEAT PRODUCTION

The daily heat production measured and that computed in the usual manner from the balance of carbon and nitrogen are compared in Table VII.

TABLE VII.—Observed and computed daily heat production

Period.	Observed.	Computed.	Error.	Computed ÷ observed.
	<i>Calories.</i>	<i>Calories.</i>	<i>Calories.</i>	<i>Per cent.</i>
I, first day.....	12,238.7	12,128.7	-110.0	99.10
I, second day.....	12,008.4	11,634.3	-374.1	96.88
II, first day.....	10,389.1	10,068.9	-320.2	96.92
II, second day.....	10,187.1	10,148.5	-38.6	99.62
III, first day.....	10,761.9	10,848.7	+86.8	100.81
III, second day.....	10,746.5	10,770.6	+24.1	100.22
IV, first day.....	13,757.7	13,574.3	-183.4	98.67
IV, second day.....	13,930.3	13,474.3	-456.0	96.73
V, first day.....	9,910.2	10,076.8	+166.6	101.68
V, second day.....	10,201.4	10,195.8	-5.6	99.95

ANALYSIS OF HEAT PRODUCTION

Standing and lying have been found to exert such an influence on the heat production of animals that in order to make comparisons the observed results must be corrected to a uniform proportion of time standing and lying. The total heat production for each day of the 2-day periods has therefore been corrected to 12 hours' standing and 12 hours' lying in the manner described in the previous paper¹ and the two days averaged, and the distribution of this corrected heat production also has been computed by the method explained on page 468 of the publication just referred to.¹ The results of these computations are recorded in Table VIII.

TABLE VIII.—Heat production per day per head corrected to 12 hours' standing

Period No.	Dry matter eaten.		Total heat production (average of 24 hours).	Distribution of heat production.			
	Hay.	Grain.		Standing.	Rising and lying down.	Fermentation.	Remainder.
	<i>Gm.</i>	<i>Gm.</i>	<i>Cal.</i>	<i>Cal.</i>	<i>Cal.</i>	<i>Cal.</i>	<i>Cal.</i>
I.....	5,952.3	.....	12,251.3	1,584.	72	777	9,818
II.....	3,941.5	.....	10,332.9	1,287	110	545	8,391
III.....	1,327.9	2,601.7	11,100.8	1,411	112	739	8,839
IV.....	2,271.7	4,363.0	14,129.0	1,879	127	1,026	11,097
V.....	908.7	1,747.5	9,854.7	1,183	113	598	7,961

¹ Armsby, H. P., and Fries, J. A. Net energy values of feeding stuffs for cattle. In Jour. Agr. Research v. 3, no. 6, p. 454. 1915.

ENERGY EXPENDITURE PER KILOGRAM OF DRY MATTER

A comparison of Periods I and II shows how much each additional kilogram of dry matter of the hay consumed increased the total heat production and its several factors (Table IX).

TABLE IX.—Computation of energy expenditure per kilogram of clover hay

Period No.	Quantity of dry matter eaten.	Total heat production	Distribution of heat production.			
			Standing.	Rising and lying down.	Fermentation.	Remainder.
	<i>Gm.</i>	<i>Cal.</i>	<i>Cal.</i>	<i>Cal.</i>	<i>Cal.</i>	<i>Cal.</i>
I.....	5,952.3	12,251.3	1,584	72	777	9,818
II.....	3,941.5	10,332.9	1,287	110	545	8,391
Difference.....	2,010.8	1,918.4	297	-38	232	1,427
Difference per kilo-gram of dry matter.....		954.0	148	-19	115	710

In making the computation for the maize meal fed in Periods III, IV, and V, when hay and meal were fed, the increase in the heat production due to the differences in the quantity of hay consumed, computed by the use of the value per kilogram of dry matter just obtained, has to be subtracted from the total increment in the manner shown in the following example (Table X):

TABLE X.—Computation of energy expenditure per kilogram of maize meal

Period No.	Quantity of dry matter eaten.		Total heat production.	Distribution of heat production.			
	Hay.	Grain.		Stand-ing.	Rising and lying down.	Fer-menta-tion.	Re-main-der.
	<i>Gm.</i>	<i>Gm.</i>	<i>Cal.</i>	<i>Cal.</i>	<i>Cal.</i>	<i>Cal.</i>	<i>Cal.</i>
Period IV.....	2,271.7	4,363.0	14,129.0	1,879	127	1,026	11,097
Period V.....	908.7	1,747.5	9,854.7	1,183	113	598	7,961
Difference.....	1,363.0	2,615.5	4,274.3	696	14	428	3,136
Difference due to 1,363.0 gm. of hay.....			1,300.3	202	-26	157	968
Difference due to 2,615.5 gm. of grain.....			2,974.0	494	+40	271	2,168
Difference per kilo-gram of grain.....			1,137.1	189	15	104	829

Six comparisons according to this method are possible, affording the results given in Table XI.

TABLE XI.—Increment of heat production per kilogram of dry matter

Feeding and period No.	Total increment.	Analysis of heat increment.			
		Standing 12 hours.	Rising and lying down.	Methane fermentation.	Remainder.
Clover hay:					
I-II.....	Cal. 954	Cal. 148	Cal. -19	Cal. 115	Cal. 710
Maize meal:					
III-II.....	1,253	196	-18	190	885
IV-II.....	1,235	192	-3	154	892
V-II.....	1,382	197	-31	230	986
IV-III.....	1,208	186	+19	101	902
III-V.....	990	194	+8	109	679
IV-V.....	1,137	189	+15	104	829
Average of all.....	1,201	192	-2	148	862
Average, omitting Periods III-II and II-V.....	1,143	190	10	117	826

The total energy expenditure per kilogram of dry matter of the clover hay, 954 Calories, agrees well with the value 992 Calories previously obtained for clover hay in experiment 179, and indicates that the very low value of 453 Calories obtained in experiment 186 was, as was suspected, erroneous.¹ It would appear that the mean of the two, 973 Calories, may be taken as the average value for red-clover hay, particularly as it is only slightly higher than that of 932 Calories computed from one of Kellner's experiments.²

The average figure for the total increment per kilogram of dry matter of maize meal eaten is 1,201 Calories, somewhat lower than the value of 1,434 Calories previously published. Another earlier experiment gave a value of 952 calories; but this was discarded, since the increment during lying (the "remainder" of Table XI) was only 393 Calories, as compared with 906 Calories in the experiment reported and 863 Calories, the average obtained in the present series.

Of the comparisons tabulated, however, Periods III-II and Periods II-V, are based on comparatively small differences in total heat production, so that the deduction for the energy expenditure due to the hay enters as a relatively large factor. If these two comparisons are omitted, the average of the remaining four is 1,143 Calories, which agrees closely with that of 1,137 Calories obtained from a comparison of the lightest and heaviest mixed rations (Periods IV-V), so that we are inclined to attach greater weight to this figure. The mean of this and the earlier experiment is 1,289 Calories, which may be taken as the corrected value for the heat production caused by the consumption of 1 kgm. of dry matter of maize meal by cattle.

¹ Armsby, H. P., and Fries, J. A. Op. cit., 1915, p. 473, 482.
² Idem., p. 478.

NET ENERGY VALUES

In computing, finally, the net energy values, by subtracting the sum of the losses of chemical energy and the energy expended in feed consumption from the gross energy of the feed, we have used first the values for the energy expended in feed consumption obtained in these experiments and then have made a second computation, using instead the average between these values and those obtained in previous experiments as computed in the foregoing paragraph. Table XII gives the final results.

TABLE XII.—Net energy values of feeding stuffs per kilogram of dry matter

Feed.	Gross energy.	Losses of chemical energy.	Energy expended in feed consumption.	Net energy values.
	Cal.	Cal.	Cal.	Cal.
Clover hay:				
These experiments.....	4,367	2,413	954	1,000
Mean.....	4,367	2,413	973	981
Maize meal:				
These experiments.....	4,501	1,297	1,143	2,061
Mean.....	4,501	1,297	1,289	1,913

SUMMARY

Results are here reported of five feeding periods with cattle, two with differing amounts of clover hay alone and three with clover hay and maize meal in differing quantities.

(1) The metabolizable energy per kilogram of digested organic matter was found to be 3.52 therms for the clover hay and 3.76 therms for the maize meal as compared with 3.49 therms and 3.80 therms, respectively, as previously reported.

(2) The average increment in heat production caused by the consumption of 1 kgm. of dry matter was as follows:

	Calories
(a) For clover hay.....	954
(b) For maize meal.....	1,143

(3) When these results are combined with those of previous experiments, the following corrected values for the average heat increment per kilogram dry matter are computed:

	Calories
(a) For clover hay.....	973
(b) For maize meal.....	1,289

(4) The average net energy values per kilogram of dry matter obtained by the use of the foregoing averages were:

	Calories
(a) For clover hay.....	981
(b) For maize meal.....	1,913

UNITED STATES DEPARTMENT OF AGRICULTURE



BULLETIN No. 459

Contribution from the Bureau of Animal Industry.
A. D. MELVIN, Chief.



Washington, D. C.

December 15, 1916

THE USE OF ENERGY VALUES IN THE COMPUTATION OF
RATIONS FOR FARM ANIMALS.¹

By HENRY PRENTISS ARMSBY, *Director of the Institute of Animal Nutrition of The Pennsylvania State College; Expert in Animal Nutrition, Bureau of Animal Industry.*

CONTENTS.

	Page.		Page.
General principles.....	1	The computation of rations—Continued.	
Components of the animal body.....	1	Improvement of a ration.....	21
Components of feeding stuffs.....	3	Computing a ration from given feeding	
The animal body as a machine.....	4	stuffs.....	22
Feed requirements.....	14	The choice of feeding stuffs.....	25
The computation of rations.....	19	The compounding of rations.....	28
General considerations.....	19	Bearing on farm management.....	29
Total feed required.....	20		

GENERAL PRINCIPLES.

COMPONENTS OF THE ANIMAL BODY.

THE MACHINERY OF THE BODY.

The essential working parts of the body contain a great variety of substances, but these may, for our present purpose, be grouped under three heads—water, ash, and protein. The bones, constituting the framework of the body; the ligaments, muscles, and tendons, which bind together and move the bones; the skin and hair, or wool, which cover and protect the body; the internal organs of circulation, respiration, digestion, excretion, and reproduction; the brain and nerves—in short, the whole mechanism of the body—can be regarded as being composed substantially of these three classes of substances.

Water.—Rarely less than half and sometimes as much as three-fourths of the weight of the live animal consists of water. The

¹ A revision of Farmers' Bulletin 346.

proportion of water is greatest in young and lean animals and decreases as they become more mature or fatter.

Ash.—The ash or mineral matter is the portion left after complete burning. Its presence is most familiar in the bones, but it is found in all parts of the body and is just as essential as water or protein. It amounts to from 2 to 5 per cent of the weight of the body.

Protein.—Protein is the name given to a highly important group of substances, of which the white of egg, washed lean meat, the casein of milk, the gluten of wheat flour, etc., are familiar examples. They are composed of the chemical elements carbon, hydrogen, oxygen, nitrogen, and sulphur. They are what are commonly called "organic" substances, which simply means that they may be burned completely in air or oxygen. They differ from the other groups of substances found in the animal body in containing sulphur, and especially nitrogen, the latter element constituting from 15 to 18 or 19 per cent of their weight.

Protein is the basis of the living tissues of the body—the so-called protoplasm—and is the substance through which life especially manifests itself. In the body it is always associated with water and ash.

THE RESERVE MATERIAL OF THE BODY

Fat.—Besides its working parts, the body contains a store of reserve material in the form of fat. While the fat deposits in the body are of use mechanically as cushions between the various organs and as a protecting layer under the skin, nevertheless fat represents essentially a storage of material derived from feed consumed in excess of the body's immediate needs. When the feed is insufficient or entirely lacking, this store of surplus material is drawn upon, and the animal gradually becomes lean. The percentage of fat in the bodies of agricultural animals may vary greatly but seldom falls below 6 or rises above 30 per cent.

Glycogen.—Besides fat there are stored up in the muscles, liver, and other organs of a healthy animal rather small amounts of a substance called "glycogen," belonging to the group of carbohydrates described in the next section. Neither fat nor glycogen contains the elements nitrogen or sulphur, but each is composed entirely of carbon, hydrogen, and oxygen.

COMPOSITION OF THE ENTIRE BODY.

The average results of analyses shown in the following table indicate the composition of the bodies of different animals in different conditions:

Percentage composition of live animals.

	Ox.			Fat calf.	Sheep.					Swine.	
	Well fed.	Half fat.	Fat.		Lean.	Well fed.	Half fat.	Fat.	Very fat.	Well fed.	Fat.
	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>
Water.....	54.3	50.2	43.6	60.1	56.6	53.7	50.7	44.8	39.0	53.9	42.0
Ash.....	4.8	4.4	3.9	4.5	3.4	3.3	3.2	2.9	2.8	2.7	1.8
Fat.....	7.1	14.9	26.8	13.1	8.6	13.2	18.3	28.1	37.2	22.5	40.2
Protein.....	15.8	15.5	13.7	15.3	15.4	14.8	13.8	12.2	11.0	13.9	11.0
Contents of stomach and intestines.....	18.0	15.0	12.0	7.0	16.0	15.0	14.0	12.0	10.0	7.0	5.0
Total.....	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

COMPONENTS OF FEEDING STUFFS.

Like the animal body, the vegetable feeding stuffs which nourish it contain a great variety of substances, but these, too, like those of the animal, may be classified into a few groups. Not only so, but these main groups are the same as those found in the animal, viz, water, ash, protein, fats, and carbohydrates. The proportions of these ingredients in the animal body and in vegetable substances, however, are widely different.

PROTEIN AND FAT.

Protein is the predominant ingredient, aside from water, in the animal body, while the latter stores up its reserve material in the form of fat, with but little carbohydrates (glycogen). Protein is also contained in all plants and, as in the animal, forms the basis of the living tissues, but the predominant ingredients as regards quantity are the carbohydrates. In the form of cellulose, or "crude fiber," they form the cell walls of the plant, while as starch and sugar they are stored up in large amounts in the cells of seeds and roots as reserve material. A few plants, like flax and cotton, store up oil instead of starch and are likewise rich in protein, but, as a rule, the common feeding stuffs contain relatively small amounts of protein and fat and are rich in carbohydrates.

The protein and fats of plants are not widely different from those of animals and call for no special description here.

CARBOHYDRATES.

The carbohydrates, as starch, sugar, etc., constitute a distinct group, represented in the animal chiefly by the small amounts of glycogen mentioned on page 2 and by the sugar of the milk. They are composed of the chemical elements carbon, hydrogen, and oxygen, the two latter being present in exactly the same relative amounts as

in water. Like the fats, they contain no nitrogen or sulphur, but they differ from the fats in containing less carbon and more oxygen.

The carbohydrates of feeding stuffs may be divided into two classes. The first of these includes those substances which are found in the cell walls and constitute the framework of the plant. This class includes cellulose and a great variety of other substances, most of which are rather difficult to dissolve. The "crude fiber" obtained in the analysis of feeding stuffs represents this class of carbohydrates.

The second class of carbohydrates consists of the reserve material stored up in the cells and includes starch, the various kinds of sugar, and other less familiar substances. Some of these carbohydrates, like the sugars, dissolve in water and all may be converted into soluble forms rather easily. In analyses of feeding stuffs they are contained in the "nitrogen-free extract" which, however, also includes a variety of other substances of ill-defined nature.

THE ANIMAL BODY AS A MACHINE.

Mechanically the body of an animal is a very wonderful machine, but what is of peculiar interest in this connection is that the body is what the engineer calls a prime motor—that is, like the steam or gasoline engine, it moves itself and may supply power to move other machines. In fact, there is in some respects a very close likeness between the animal body and what are known as internal-combustion motors, i. e., those engines in which power is developed by burning liquid or gaseous fuel (gasoline, alcohol, producer gas, etc.) in the cylinder of the engine itself. Such an engine requires two things for its operation: (1) Sufficient repair material to keep its working parts in running order, and (2) a supply of fuel in proportion to the work to be done. Just these same two things are what the animal requires—repair material and fuel.

In one respect, however, the animal body differs from the artificial machine—it can not be stopped and started again at will. As long as the animal lives the vital machinery is in operation, although less actively at some times than at others. The animal might be compared to an automobile whose engine must be kept running at a low speed in order to have the power available when needed. Consequently, the animal requires to be supplied with repair material and with fuel as long as it lives and not merely when it is in active use.

That the feed of the animal is its source of both repair material and fuel is sufficiently obvious. We do not need a physiologist to tell us that when an animal is deprived of feed its tissues waste away while its fat is burned up in the effort to keep the bodily machinery in motion. We may proceed at once, therefore, to consider the feed in these two relations.

THE DEMAND FOR REPAIR MATERIAL.

The repair material for any machine must be of the same kind of which the machine is made. We have just seen that the machinery of the body is composed of protein, ash, and water. These, then, are the materials which must be supplied to keep it in repair.

Water, of course, is or should be abundantly supplied in the drink and scarcely need be considered in a discussion of rations.

Ash.—The ash supply has received less attention in the past than its importance deserves. In the ordinary operation of the bodily machinery its ash ingredients are being continually excreted and the feed must supply ash sufficient in amount and of the right kinds to make good the loss, while the growing animal needs an additional supply for building up its new tissues. Fortunately, normally constituted rations appear rarely to be deficient in ash. Usually it is only when large amounts of certain by-product feeds are used or when there is a misrelation between grain and coarse fodder that special attention needs to be given to the ash supply.

Protein.—The protein supply, on the other hand, calls for careful consideration. Protein is the characteristic ingredient of the animal mechanism and is broken down and destroyed in its operation at a fairly regular rate. Moreover, since the bodily machinery is running all the time, whether any external work is done or not, this loss is continually going on.

The body differs from a machine in being self-repairing, but it can not manufacture protein for repair purposes out of the carbohydrates and fats of its feed any more than it is possible to make repairs for an automobile out of the gasoline which supplies the power. For its protein the body is absolutely dependent on the protein of the feed. This protein is needed for two purposes.

First. It is required for repair purposes in the strict sense; i. e., for making good the wear and tear of the bodily machinery. The amount needed for this purpose is comparatively small, and is no greater under normal conditions when the animal is doing work than when it is not. Like a good engine, the body makes relatively small demands for repair material and requires chiefly fuel.

Second. Protein as well as ash is needed in the growing, pregnant, or milking animal to furnish the material for enlarging the working machinery of the body of the animal itself or of its young. The amount of protein required for this purpose is just so much in addition to that needed for repair purposes simply, and hence the feed of these animals must contain a more liberal supply of this ingredient. This is important physiologically to secure proper nutrition of the young and economically because the growth or milk produced is the principal object of the feeder.

FEED AS A SOURCE OF REPAIR MATERIAL.

For the reasons stated on page 5, the ash has generally been omitted from consideration in discussing the feed as a source of repair material.

The value of a feeding stuff as a source of protein to the animal body depends in the first place on the amount of protein which it contains. Cottonseed meal, carrying some 43 per cent of protein, is evidently, other things being equal, a better source of protein than Indian corn, carrying about 10 per cent.

In the second place, however, the protein of the feeding stuff must be capable of being digested by the animal. Of two feeding stuffs containing equal amounts of protein, that one is the more valuable as a source of supply in which the larger proportion of the protein is digestible. The second and third columns of the table on pages 11-13 show the average percentages of digestible "crude" and "true" protein contained in a number of the more common feeding stuffs. These figures are the average results of a considerable number of analyses of the feeding stuffs and a smaller number of determinations of their digestibility. Individual samples may vary more or less, and sometimes considerably, from the average.

A third question is at once suggested, viz, whether the digestible protein from different feeding stuffs is equally valuable to the animal. Recent investigations have shown that this is not the case. Single proteins have been found to vary widely in nutritive value, and in particular the mixed proteins of the cereals appear to be of somewhat inferior quality. In ordinary mixed rations, however, it appears doubtful whether these differences are of very much practical significance. At any rate, pending further investigation, the only course which seems open at present is to assume the proteins of the various feeding stuffs to be of substantially equal value.

THE DEMAND FOR FUEL MATERIAL.

Since the animal machinery is running continually, it requires a continual supply of fuel material, the amount which is necessary depending upon the amount of work done. This fuel material consists chiefly of the carbohydrates and fats of the feed, although if more protein be fed than is required for repair and construction purposes it, too, may be used as fuel, while the worn-out portions of the protein tissues are also utilized—that is, the bodily engine can burn up its own waste products as fuel. The unnecessary use of protein as fuel material, however, is wasteful, because protein is ordinarily more expensive to buy or to produce on the farm than are carbohydrates and fats.

If the fuel materials supplied in the feed are just adequate to the work to be done, they are virtually burned up as a source of power. If more are supplied than are immediately needed, the body is able to store away the surplus for future use, much as we may fill up the gasoline tank of an engine. To a small extent the body stores up carbohydrates (in the form of glycogen), but most of its surplus fuel it converts into fat. The fat of the body, therefore, is its reserve of fuel. In fattening, the body is accumulating a surplus against future needs which man diverts to his own use as food. If the feed becomes insufficient, this store is drawn upon and the animal gradually becomes lean. Similarly, in growth and in milk production, the animal sets aside a part of the supply of both repair and fuel material in its feed for its own growth or for the use of its young, and man appropriates the resulting meat or milk as repair and fuel material for his own body.

FEED AS A SOURCE OF FUEL MATERIAL.

We can run an engine with various kinds of fuel. For the steam engine we may use coal or wood or petroleum; for the internal-combustion motor, gas, alcohol, or gasoline may be employed. Similarly, we supply the animal body with a great variety of feeding stuffs from which it has to extract its supply of fuel, and even the materials which it actually burns up are of various sorts.

These fuel materials are not all of equal value. A pound of good anthracite coal, for example, is, other things being equal, about 14 per cent more valuable as fuel than the same weight of alcohol, while a pound of fat in the feed has over twice the fuel value of a pound of starch. Evidently, it will greatly simplify comparisons of different feeding stuffs and rations as sources of fuel material to have some simple method by which we can learn not only the amount of fuel material which the feed contains, but also the quality of that fuel. Such a basis of comparison is afforded by a study of the energy values.

MEASUREMENT OF ENERGY.

Anything which has the capacity to do work is said to possess energy. Hence we say that the fuel of the engine and the feed of the animal possess energy, since they enable the engine or the body to do work. They hold this energy stored up in the "latent" or "potential" form of chemical energy. When they are burned in the engine or the body, this chemical energy is set free, part of it being converted into work and the rest escaping as heat.

Plainly, then, the value of a fuel, or of a feeding stuff so far as it serves as fuel, depends, in the first place, on how much chemical energy it contains. This can be measured without difficulty by con-

verting it all into heat, by burning the substance, and measuring the heat produced. Various units have been employed in measuring heat, but the one used in this bulletin is the therm.

A therm¹ is the quantity of heat required to raise the temperature of 1,000 kilograms (2,204.6 pounds) of water 1° C. A pound of good anthracite coal would produce heat enough to raise the temperature of about 3,583 kilograms of water 1° C. Consequently, the chemical energy contained in the coal is 3.583 therms per pound. In precisely the same way the amount of chemical energy contained in many feeding stuffs has been measured. The following are the results of a few such determinations:

Chemical energy in 100 pounds.²

	Therms.
Timothy hay.....	175.1
Clover hay.....	173.2
Oat straw.....	171.0
Wheat straw.....	171.4
Corn meal.....	170.9
Oats.....	180.6
Wheat bran.....	175.5
Linseed meal.....	196.7

UTILIZATION OF ENERGY.

But the value of a fuel depends also upon how much of the chemical energy which it contains can be used. Hard coal contains plenty of energy, but it would not be of much use to run a gasoline engine. Wheat straw contains fully as much chemical energy as corn meal, but much of that energy can not be utilized by the animal machine.

Two causes combine to affect the utilization of the chemical energy contained in feeding stuffs.

First, more or less of the feed escapes from the body unburned. If a coal is of such quality that portions of it drop through the grate unconsumed, and if smoke and combustible gases are carried off through the stack, it is evident that a ton of it will supply far less heat to the boiler than it would if the combustion were perfect. The case of the feeding stuff is similar. Much of even the best feeding stuffs escapes digestion and is excreted in the dung, carrying with it a corresponding quantity of the chemical energy of the feed. More

¹ In the nutrition investigations and studies of foods and feeding stuffs made by this department and by the State agricultural experiment stations, the results, so far as energy or fuel value is concerned, have been expressed in calories, the unit so used being the large or kilogram calorie, as distinguished from the small or gram calorie. There is consequently a large mass of available data so expressed. The calorie thus used is the amount of heat required to raise 1 kilogram of water 1° C. (approximately 1 pound of water 4° F.). The small size of the unit has made it necessary to use inconveniently large numbers to express the fuel values of foods and feeding stuffs, a difficulty which is obviated by the use of the therm. As the latter unit is equivalent to 1,000 large calories, available data, such, for example, as those in Farmers' Bulletin 22, can be readily given expression in the new unit. The use of the word therm, with the abbreviation *t.*, has also been proposed as the equivalent of the small (or gram) calorie, but it has not come into general use.

² With 15 per cent moisture.

or less incompletely burned material is also contained in the urine, while ruminants, and to a certain extent horses and swine, also give off combustible gases arising from fermentations in the digestive tract. Thus about 22 per cent of the chemical energy of corn meal and fully 55 per cent of that of average hay has been found to escape in these ways.

Second, as already pointed out, the animal body has to extract its real fuel material from its feed, separating it from the relatively large proportion of useless material which it excretes. To effect this separation requires work and consumes energy, and this energy, of course, is not available for other purposes. The case is somewhat as if the gasoline engine had to distill its own gasoline and separate it from impurities. Moreover, it appears to be well established that the digestible substances taken up from the alimentary tract act as a direct stimulus to the combustions going on in the body; that is, that the body may burn up more material simply because a larger supply is available, while there is some evidence that an increase in the feed consumed tends to stimulate the minor incidental movements of the animal, or, in other words, to render the animal more restless, especially when standing.

It is not, then, the total chemical energy contained in a feeding stuff which measures its value as fuel material to the body, but what remains after deducting the losses in the unburned materials of the excreta and the energy expenditure incident to the consumption of the feed. This remainder is called its net energy.

For example, while 100 pounds of corn meal contain, as stated, about 170.9 therms of chemical energy, only about 88.8 therms remain, after all these deductions have been made, to represent the actual value of the corn meal as a source of energy to the organism.

NET ENERGY VALUES OF FEEDING STUFFS.

While it is a comparatively simple matter to ascertain the total amount of chemical energy contained in a feeding stuff, the determination of the proportion of this energy which the body can actually utilize, i. e., its net energy value, requires the use of complicated and costly apparatus (respiration apparatus or respiration calorimeter) and the expenditure of much time and labor. While much has been accomplished along this line, vastly more still remains to be done before we can claim to have a complete knowledge of the energy values of feeding stuffs. At the same time, enough has already been accomplished, through the investigations of G. Kühn and of Kellner at the Möckern Experiment Station in Germany, since 1882, and by the experiments carried on, in cooperation with this Department, by the Institute of Animal Nutrition of The Pennsylvania State College, to demonstrate that the method still generally current of

comparing feeding stuffs on the basis of the digestible matter which they contain is seriously erroneous and to permit the computation of at least tentative net energy values. A summary of the results of these investigations has been published in Bulletin 142 of the Pennsylvania Experiment Station together with an outline of the methods used for computing the net energy values of feeding stuffs which have not been the subject of direct experiment.

Henry and Morrison¹ have recently published a very valuable compilation of American analyses of feeding stuffs and of the results of American digestion experiments, and on this basis have calculated the content of digestible nutrients (for ruminants) in a great variety of feeding stuffs.

With the permission of these authors, the writer, in cooperation with Prof. F. S. Putney, of The Pennsylvania State College, has computed from their tables the net energy values of the more important feeding stuffs with the results contained in the following table, which includes the digestible (true) protein and also the nonprotein estimated on the basis of Kellner's averages. In regard to this table it is to be remarked—

First. Both the digestion coefficients used by Henry and Morrison and the data for the expenditure of energy due to feed consumption are derived exclusively from experiments on ruminants (cattle). Consequently, the net energy values here computed are directly applicable to ruminants only.

Second. The table shows primarily the net energy values for maintenance or fattening. There seems good reason for believing, however, that they may be taken without serious error to represent also the net energy values for growth and at least the relative values for milk production. Kellner believes that the same net energy values may also be regarded as expressing with sufficient accuracy the relative values of feeding stuffs for horses and for swine. The requirements for these animals, therefore, as tabulated on the following pages, are substantially those given by Kellner.

¹ Feeds and Feeding, 15th edition, pp. 638-666.

Average dry matter, digestible crude protein, digestible true protein, and net energy values per 100 pounds of feeding stuffs for ruminants.

	Dry matter.	Digestible.		Net energy value.
		Crude protein.	True protein.	
DRIED ROUGHAGE.				
<i>Hay and fodder from cereals.</i>				
	Pounds.	Pounds.	Pounds.	Therms.
Brome grass, smooth.....	91.5	5.0	3.5	40.83
Corn fodder (ears included, medium dry).....	81.7	3.0	2.3	43.94
Corn stover (ears removed, medium dry).....	81.0	2.1	1.6	31.62
Millet, Hungarian.....	85.7	5.0	3.9	46.96
Mixed timothy and clover.....	87.8	5.3	3.2	41.07
Oat hay.....	88.0	4.5	3.9	32.25
Orchard grass.....	88.4	4.7	3.3	44.93
Redtop.....	90.2	4.6	3.9	51.22
Timothy, all analyses.....	88.4	3.0	2.2	43.02
Timothy, before bloom.....	92.8	4.7	2.9	43.52
Timothy, early to full bloom.....	87.2	3.6	2.5	47.40
Timothy, late bloom to early seed.....	85.1	2.4	1.8	37.54
Timothy, nearly ripe.....	87.5	2.2	1.8	38.59
<i>Hay and fodder from legumes.</i>				
Alfalfa, all analyses.....	91.4	10.6	7.1	34.23
Alfalfa, before bloom.....	93.8	15.4	10.3	36.23
Alfalfa, in bloom.....	92.5	10.5	6.7	32.33
Alfalfa, in seed.....	89.6	8.5	6.2	32.23
Clover, alsike.....	87.7	7.9	5.3	34.42
Clover, crimson.....	89.4	9.7	6.9	36.21
Clover, red, all analyses.....	87.1	7.6	4.9	38.68
Clover, red, before bloom.....	89.6	11.6	5.4	42.17
Clover, red, in bloom.....	86.1	8.1	5.3	39.12
Clover, red, after bloom.....	77.9	6.8	4.5	34.51
Clover, sweet white.....	91.4	10.9	6.7	38.98
Cowpeas, all analyses.....	90.3	13.1	9.2	37.59
Cowpeas, before bloom.....	92.2	17.8	12.8	33.54
Cowpeas, in bloom to early pod.....	89.4	12.6	9.5	39.11
Soy beans.....	91.4	11.7	8.8	44.03
<i>Straws.</i>				
Barley.....	85.8	.9	.6	36.61
Buckwheat.....	90.1	4.2	3.2	4.55
Oat.....	88.5	1.0	.8	34.81
Rye.....	92.9	.7	.5	17.59
Wheat.....	91.6	.7	.3	7.22
FRESH GREEN ROUGHAGE.				
<i>Green cereals, etc.</i>				
Barley fodder.....	23.2	2.3	2.0	14.08
Bluegrass, Kentucky, before heading.....	23.8	3.7	2.8	14.82
Bluegrass, Kentucky, headed out.....	36.4	2.8	2.2	17.77
Bluegrass, Kentucky, after bloom.....	43.6	1.9	1.6	21.01
Buckwheat, Japanese.....	36.6	2.2	1.5	17.78
Cabbage.....	8.9	1.9	1.3	8.87
Cabbage, waste outer leaves.....	14.1	1.7	1.1	7.05
Corn fodder, dent, all analyses.....	23.1	1.0	.8	14.60
Corn fodder, dent, in tassel.....	14.9	1.1	.8	9.52
Corn fodder, dent, in milk.....	19.9	1.0	.8	13.64
Corn fodder, dent, dough to glazing.....	25.1	1.3	1.0	17.35
Corn fodder, dent, kernels glazed.....	26.2	1.1	.8	16.74
Corn fodder, dent, kernels ripe.....	34.8	1.5	1.1	22.48
Corn fodder, flint, all analyses.....	20.7	1.0	.8	13.53
Corn fodder, flint, in tassel.....	10.6	.9	.7	6.89
Corn fodder, flint, in milk.....	15.0	.9	.7	10.39
Corn fodder, flint, kernels glazed.....	21.0	1.0	.8	13.49
Corn fodder, flint, kernels ripe.....	27.9	1.2	.9	17.84
Corn fodder, sweet, before milk stage.....	10.0	.8	.6	7.82
Corn fodder, sweet, roasting ears or later.....	20.3	1.2	.9	13.38
Corn fodder, sweet, ears removed.....	21.5	1.0	.8	14.26
Millet, Hungarian.....	27.6	1.9	1.1	17.24
Oat fodder.....	26.1	2.3	2.0	14.06
Orchard grass.....	29.2	1.7	1.1	15.81
Rape.....	16.7	2.6	1.7	13.07
Rye fodder.....	21.3	2.1	1.4	15.99
Sweet sorghum fodder.....	24.9	.7	.4	15.37
Timothy, before bloom.....	24.2	1.8	1.1	18.36
Timothy, in bloom.....	32.1	1.3	.8	18.89
Timothy, in seed.....	46.4	1.5	1.0	26.35
Wheat fodder.....	27.4	2.8	1.9	18.75

Average dry matter, digestible crude protein, digestible true protein, and net energy values per 100 pounds of feeding stuffs for ruminants—Continued.

	Dry matter.	Digestible.		Net energy value.
		Crude protein.	True protein.	
FRESH GREEN ROUGHAGE—continued.				
Green legumes.				
	Pounds.	Pounds.	Pounds.	Threms.
Alfalfa, before bloom.....	19.9	3.5	1.9	9.20
Alfalfa, in bloom.....	25.9	3.3	1.8	11.50
Alfalfa, after bloom.....	29.8	2.1	1.3	11.10
Clover, alsike.....	24.3	2.7	1.5	14.56
Clover, crimson.....	17.4	2.3	1.6	10.83
Clover, red, all analyses.....	26.2	2.7	1.7	15.87
Clover, red, in bloom.....	27.5	2.7	1.8	16.74
Clover, red, rowen.....	34.4	3.3	2.2	17.30
Cowpeas.....	16.3	2.3	1.7	10.42
Peas, Canada field.....	16.6	2.9	2.1	9.78
Soy beans, all analyses.....	23.6	3.2	2.4	12.53
Soy beans, in bloom.....	20.8	3.0	2.3	10.44
Soy beans, in seed.....	24.2	3.1	2.5	12.70
Vetch, hairy.....	18.1	3.5	2.4	11.95
SILAGE.				
Corn, well matured, recent analyses.....	26.3	1.1	.6	15.90
Corn, mature.....	21.0	1.0	.4	11.96
Corn, from frosted ears.....	25.3	1.2	.6	14.27
Corn, from field-cured stover.....	19.6	.5	.3	8.98
Clover.....	27.8	1.3	.8	7.26
Cowpeas.....	22.0	1.8	1.1	11.05
Soy beans.....	27.1	2.6	1.5	11.59
Sugar-beet pulp.....	10.0	.8	.5	9.32
ROOTS, TUBERS, AND FRUITS.				
Apple.....	18.2	.4	.1	15.92
Beet, common.....	13.0	.9	.1	7.84
Beet, sugar.....	16.4	1.2	.4	11.20
Carrot.....	11.7	.9	.5	9.21
Mangels.....	9.4	.8	.1	5.68
Potatoes.....	21.2	1.1	.1	18.27
Pumpkin, field.....	8.3	1.1	.6	6.05
Rutabaga.....	10.9	1.0	.3	8.46
Turnip.....	9.5	1.0	.4	6.16
GRAINS.				
Cereal grains.				
Barley.....	90.7	9.0	8.3	89.94
Buckwheat.....	87.9	8.1	7.2	59.73
Corn, dent.....	89.5	7.5	7.0	89.16
Corn, flint.....	87.8	7.7	7.2	87.50
Corn-and-cob meal.....	89.6	6.1	5.7	75.80
Corn meal.....	88.7	6.9	6.4	88.75
Oats.....	90.8	9.7	8.7	67.56
Oatmeal.....	92.1	12.8	11.5	86.20
Rye.....	90.6	9.9	9.0	93.71
Wheat, all analyses.....	89.8	9.2	8.1	91.82
Wheat, winter.....	89.1	8.7	7.7	91.06
Wheat, spring.....	89.9	9.2	8.1	91.41
Leguminous seeds.				
Bean, navy.....	86.6	18.8	16.4	73.29
Cowpea.....	88.4	19.4	16.9	79.46
Pea, field.....	90.8	19.0	16.6	78.72
Pea meal.....	89.1	19.8	17.2	77.62
Peanut, with hull.....	93.5	19.4	16.9	83.15
Peanut kernel.....	94.0	24.1	22.2	109.04
Soy bean.....	90.1	30.7	27.3	81.29
Oil seeds.				
Cotton seed.....	90.6	13.3	11.9	78.33
Flaxseed.....	90.8	20.6	19.2	83.17
Sunflower seed.....	95.5	23.3	20.2	95.77
Sunflower seed, with hulls.....	93.1	13.5	11.7	92.49

Average dry matter, digestible crude protein, digestible true protein, and net energy values per 100 pounds of feeding stuffs for ruminants—Continued.

	Dry matter.	Digestible.		Net energy value.
		Crude protein.	True protein.	
DAIRY PRODUCTS.				
	Pounds.	Pounds.	Pounds.	Threms.
Buttermilk.....	9.4	3.4	3.4	13.32
Cow's milk.....	13.6	3.3	3.3	29.01
Skim milk, centrifugal.....	9.9	3.6	3.6	14.31
Skim milk, gravity.....	9.6	3.1	3.1	15.43
Skim milk, dried.....	91.7	34.4	34.4	103.91
Whey.....	6.6	.8	.8	10.39
BY-PRODUCTS.				
Fermentation industries.				
Brewers' grains, dried.....	92.5	21.5	20.2	53.38
Brewers' grains, dried, below 25 per cent protein.....	91.8	18.7	17.5	50.93
Brewers' grains, wet.....	24.1	4.6	4.4	14.53
Distillers' grains, dried, from corn.....	93.4	22.4	18.3	85.08
Distillers' grains, dried, from rye.....	92.8	13.6	11.1	56.01
Distillers' grains, wet.....	22.6	3.3	2.8	22.05
Malt.....	94.2	15.8	11.8	87.82
Malt sprouts.....	92.4	20.3	12.5	72.72
Milling.				
Buckwheat bran.....	88.8	10.5	9.1	30.59
Buckwheat hulls.....	89.7	.4	(?)	-7.69
Buckwheat middlings.....	88.0	24.6	20.8	72.19
Hominy feed.....	89.9	7.0	6.5	81.31
Rye bran.....	88.6	12.2	10.5	79.35
Wheat bran.....	89.9	12.5	10.8	53.00
Wheat middlings, flour.....	89.3	15.7	14.0	75.02
Wheat middlings, standard.....	89.6	13.4	12.0	59.10
Oil extraction.				
Coconut meal, low in fat.....	90.4	18.8	18.3	83.49
Coconut meal, high in fat.....	92.3	18.4	18.0	100.31
Cottonseed hulls.....	90.3	.3	(?)	9.92
Cottonseed meal, choice.....	92.5	37.0	35.4	93.46
Cottonseed meal, prime.....	92.2	33.4	32.0	90.00
Germ oil meal, corn.....	91.1	16.5	14.3	83.88
Linseed meal, new process.....	90.4	31.7	30.9	85.12
Linseed meal, old process.....	90.9	30.2	28.5	88.91
Palm-nut cake.....	89.6	12.4	12.0	94.18
Peanut cake from hulled nuts.....	89.3	42.8	41.4	93.55
Peanut cake, hulls included.....	94.4	20.2	19.5	42.57
Soy-bean meal, fat extracted.....	88.2	38.1	37.3	99.65
Sunflower seed, cake.....	90.0	32.0	29.1	88.87
Starch manufacture.				
Gluten feed.....	91.3	21.6	20.1	80.72
Gluten meal.....	90.9	30.2	28.1	84.15
Starch feed, dry.....	90.7	11.2	9.2	77.46
Starch feed, wet.....	33.4	4.1	3.7	30.45
Sugar manufacture.				
Molasses, beet.....	74.7	1.1	.0	57.10
Molasses, cane or blackstrap.....	74.2	1.0	.0	55.38
Molasses, beet-pulp.....	92.4	5.9	3.5	76.28
Sugar-beet pulp, dried.....	91.8	4.6	.7	75.87
Sugar-beet pulp, ensiled.....	10.0	.8	.5	9.32
Sugar-beet pulp, wet.....	9.3	.5	.5	8.99
Packing house.				
Dried blood.....	90.3	69.1	68.6	68.12
Tankage:				
Over 60 per cent protein.....	92.6	58.7	55.6	93.04
55 to 60 per cent protein.....	92.5	54.0	51.1	83.58
45 to 55 per cent protein.....	92.5	48.1	45.5	72.96
Below 45 per cent protein.....	93.5	37.6	35.6	54.16

FEED REQUIREMENTS.

Assuming that the foregoing table represents with a fair degree of accuracy the amount of repair material (protein) on the one hand and of energy on the other which the various feeding stuffs can supply, we still need to know how much of each is required by the bodies of animals of different kinds and kept for different purposes; in other words, we need some formulation of the feed requirements of farm animals.

REQUIREMENTS FOR MAINTENANCE.

Since the animal machine may not be stopped when it is not in active use, it requires, as was pointed out on page 4, and as is a familiar fact of experience, a continual supply of feed. This amount of feed, which is required simply to support the animal, is commonly designated as the "maintenance requirement"—that is, it is the amount required simply to maintain the animal when it is doing no work and producing nothing. In other words, it is the least amount on which life can be permanently maintained.

The maintenance requirement is naturally greater for a large than for a small animal. Experiment has shown, however, that this increase is not proportional to the weight of the animal, but approximately to the amount of surface which it exposes, so that the large animal requires less feed in proportion to its weight to maintain it than does the small one.

The following tables show the amounts of protein and of net energy required per head for the maintenance of cattle, sheep, and horses of different weights. The figures given for sheep include a sufficient allowance for the normal growth of wool. No very satisfactory figures for swine are available. It should be understood that strict accuracy is not claimed for these figures, although they are substantially correct. In particular there seems to be reason to believe that the maintenance requirement of fattening animals increases somewhat more rapidly than these tables indicate.

Maintenance requirements of cattle and horses, per day and head.

Live weight.	Cattle.		Horses.	
	Digestible protein.	Net energy value.	Digestible protein.	Net energy value.
Pounds.	Pounds.	Therms.	Pounds.	Therms.
150	0.15	1.70	0.18	2.10
250	.20	2.40	.24	2.90
500	.30	3.80	.36	4.60
750	.40	4.95	.48	6.00
1,000	.50	6.00	.60	7.30
1,250	.60	7.00	.72	8.50
1,500	.65	7.90	.78	9.60

Maintenance requirements of sheep, per day and head.

Live Weight.	Digestible protein.	Net energy value.
Pounds.	Pounds.	Therms.
20	0.013	0.30
40	.028	.54
60	.039	.71
80	.050	.87
100	.055	1.00
120	.061	1.13
140	.072	1.25

REQUIREMENTS FOR GROWTH.

While young animals gain in weight faster than do older ones, a pound of increase in live weight in the young animal contains much more water and less dry matter than in the case of a more mature animal. Moreover, the dry matter in the case of the young animal contains relatively more protein and less fat, as a rule, than in the older one, and fat contains much more chemical energy than protein, the proportion being 1 to 1.67. The consequence is that a gain of 1 pound in live weight represents the storing up of much less energy in the young than in the mature animal, and therefore requires a smaller supply of energy in the feed.

Unfortunately no very extensive determinations of the composition and energy values of the increase of live weight in growing animals have yet been reported. The following estimates by the writer, derived from such data as are available, may serve to give a general idea of the requirements per pound of growth of cattle and sheep at different ages, but they can not lay claim to any high degree of accuracy. The figures refer to normal growth, with no considerable fattening.

Estimated energy value of 1 pound of gain in weight by growing cattle and sheep.

Age.	Net energy value.
Months.	Therms.
3	1.50
6	1.75
12	2.00
18	2.50
24	2.75
30	3.00

The growing animal also requires a sufficient supply of digestible protein for maintenance and to supply material for new growth. No very systematic study of the latter requirement has yet been made, but from the results of a considerable number of practical feeding trials it is possible to make a fairly satisfactory estimate of the total

amounts of digestible protein which should be contained in the rations of cattle and sheep at different ages to insure satisfactory growth. These estimates are contained in the following table. They are expressed in pounds per head and include the maintenance requirement. As a matter of convenience, the table also contains the estimated net energy values required per head for normal growth, and it thus constitutes a set of approximate feeding standards. In their use the weight rather than the age of the animal should be the controlling factor.

Estimated requirements¹ per day and head.

FOR GROWING CATTLE.

Age.	Beef breeds.			Dairy breeds.		
	Live weight.	Digestible protein.	Net energy value.	Live weight.	Digestible protein.	Net energy value.
Months.	Pounds.	Pounds.	Therms.	Pounds.	Pounds.	Therms.
3	200	0.80	4.2	165	0.65	3.6
6	350	1.10	5.0	275	.85	4.1
9	450	1.25	5.7	325	.90	4.4
12	550	1.40	6.5	400	1.00	5.1
18	750	1.50	8.2	550	1.10	6.4
24	900	1.60	9.3	700	1.20	7.6
30	1,000	1.60	9.9	800	1.20	8.2

FOR GROWING SHEEP.

Age.	Mutton breeds.			Wool breeds.		
	Live weight.	Digestible protein.	Net energy value.	Live weight.	Digestible protein.	Net energy value.
Months.	Pounds.	Pounds.	Therms.	Pounds.	Pounds.	Therms.
6	72	0.31	1.05	65	0.28	0.95
9	98	.27	1.20	82	.23	1.05
12	115	.24	1.35	90	.20	1.15
15	130	.24	1.50	95	.18	1.18
18	150	.23	1.65	100	.15	1.20

¹ Including the maintenance requirement.

No satisfactory data for colts are available, while, as noted on page 10, our knowledge of the relative values of feeding stuffs for swine is somewhat deficient.

REQUIREMENTS FOR FATTENING.

The foregoing data refer to what might be called normal growth, in which the animals are kept in a good thrifty condition, but do not become fat. If any considerable fattening is desirable, somewhat heavier rations must be given in proportion to the amount of gain made, because the increase gain in fattening animals consists to a very large extent of fat and therefore means the storing up by the animal of more reserve energy. For fairly mature fattening ani-

mals—such, for example, as the 2 to 3-year-old steers which are commonly fattened in the corn belt—probably 3.25 therms of net energy per pound of gain in live weight is a fair allowance, although more appears to be often used in practice. As yet no corresponding data are available for the fattening of growing animals, as, for example, in the production of the so-called baby beef. It is not probable, however, that any larger amount of protein is required in such fattening than in feeding simply for normal growth, so that the additional feed given for fattening may, from this point of view, consist largely of nonnitrogenous material; that is, carbohydrates and fats. It is to be noted, however, that an excess of these materials in the ration tends to cause less perfect digestion and also that a moderate proportion of the more nitrogenous concentrates seems to promote the consumption of heavy rations. Kellner recommends that at least 1 pound of digestible protein be supplied in the ration for each 8 to 10 pounds of carbohydrates and fat.

REQUIREMENTS FOR MILK PRODUCTION.

Of all forms of animal production that of milk is perhaps the most variable and most influenced in its amount by the feed supply. The energy relations of milk production have not been very fully investigated. Tentatively, however, it seems safe to estimate that the production of 1 pound of average milk, containing about 13 per cent of total solids and 4 per cent of fat, will require approximately 0.27 therm of net energy value in the feed. Naturally this amount would vary with the quality of the milk, milk rich in fat and in total solids requiring more than milk containing more water or a lower percentage of fat.

The matter of the protein requirements for milk production has not been altogether cleared up. It seems to have been pretty well demonstrated that, for a time at least, a moderate milk production may be kept up on a supply of protein only slightly exceeding that found in the milk produced (of course, in addition to the maintenance requirement). In the case of average milk, this would call for about 0.032 pound of digestible protein for each pound of milk. It has not been demonstrated, however, that a cow can keep this up indefinitely. Furthermore, for the production of liberal yields of milk more protein seems to be required, or at least to be advantageous.

Tentatively, the requirements of digestible true protein and of net energy for the production of 1 pound of milk may be formulated as follows.

Requirements for the production of 1 pound of milk.

Fat in milk.	Requirements.	
	Digestible protein.	Net energy value.
<i>Per cent.</i>	<i>Pounds.</i>	<i>Therms.</i>
2.5	0.041	0.19
3.0	.043	.21
3.5	.045	.24
4.0	.049	.27
4.5	.052	.29
5.0	.055	.32
5.5	.058	.34
6.0	.061	.36
6.5	.064	.39
7.0	.068	.41

REQUIREMENTS FOR WORK.

Since the horse (or mule) is the usual working animal in the United States, consideration will be limited to this animal.

There is on record a considerable amount of data as to the relation between the work performed by the horse and the amount of energy necessary to be supplied in the feed. Where large numbers of horses are kept and the work is relatively uniform in amount, it is possible to make fairly satisfactory computations from these data, although the method is somewhat complicated. The amount of work required of farm horses, however, is so varied in amount and kind and so difficult of measurement or estimate as regards amount, that it is scarcely practicable to base the calculation of rations upon it. The table on pages 11-13 probably shows with at least a fair degree of accuracy the relative values of different feeding stuffs as sources of energy for work production, while the amount to be fed will ordinarily be based upon the observation of the feeder rather than upon arithmetical calculations. As a sort of general average, however, Kellner recommends the following rations for a 1,000-pound horse, the amounts stated including the maintenance requirement:

Requirements of the working horse.

	Digestible protein.	Net energy value.
	<i>Pounds.</i>	<i>Therms.</i>
For light work.....	1.0	9.80
For medium work.....	1.4	12.40
For heavy work.....	2.0	16.00

DRY MATTER IN RATIONS.

The total volume of feed which an animal requires, although rather variable, has its limits. In computing rations the most convenient indication of the bulk of the feeds is the percentage of dry

matter shown in the first column of the table on pages 11-13. In very general terms it may be said that a 1,000-pound ruminant should be given from 20 to 30 pounds of dry matter per day, 25 pounds being perhaps a fair average, while for the horse smaller amounts will be appropriate.

A study of the table shows that concentrated feeding stuffs contain much more protein and energy in proportion to their dry matter than do the forage crops. Evidently, then, in heavy feeding, where the purpose is to give the animal all the feed possible, the ration should consist as largely as practicable of concentrated feeding stuffs, because only in that way can the required amount of nutriment be obtained without unduly increasing the bulk of the ration. On the other hand, in light feeding the coarse fodders may predominate, because they are usually relatively cheaper and can supply the required amount of nutriment in a bulk which the animal can consume.

THE COMPUTATION OF RATIONS.

GENERAL CONSIDERATIONS.

In the foregoing pages we have considered the requirements of the animal machine for repair material (protein), and for fuel material (energy), and have also studied the feed as a source of these two. If we knew exactly the requirements of the animal in any given case, and if we knew exactly what amounts of protein and energy the feeding stuffs at our disposal could furnish, the computation of a ration would be almost purely a matter of arithmetic. We would simply have to devise a mixture of the feeding stuffs which would yield the requisite amounts of protein and energy and would at the same time be of suitable bulk and of such a character as to exert no injurious action upon the animal.

As a matter of fact, we have no such exact knowledge. Practically, animals vary in their requirements, while feeding stuffs of the same name show a wide range in composition, digestibility, and nutritive value. Furthermore, what is still more important, the economic conditions vary from case to case so that, for example, a very liberal ration might be advisable in one instance, while for the same animal under different conditions it would be highly uneconomic. The figures given on previous pages can not be made the basis of infallible recipes which shall save the user the trouble of observing and thinking.

But notwithstanding all this, the foregoing data can afford valuable aid to the feeder. By their use he can get a general idea of the feed requirements of his animals and can compute a ration which will approximately supply the requisite amounts of protein and energy. His ability as a feeder will be shown, first, in his power

to estimate the conditions which will modify the feed requirements of his particular animals and cause his feeds to vary from the average, and, second, in the skill with which he can interpret the daily results and modify his feeding in accordance with them.

The problems given on the following pages are intended simply as illustrations of the method of using the tables and not as model rations. Limitations of space forbid the multiplication of examples, but the reader who grasps the method will have no serious difficulty in applying it to his own conditions, while facility will be acquired with surprising rapidity by practice. It will be observed that the form of these tables and the methods of computation do not differ materially from those which have been used for many years in computing rations on the basis of "digestible nutrients," although the significance of some of the figures is different. It may be added that the digestible protein in the tables is true protein—that is, it does not include the so-called "amids" of the "crude protein." Consequently the percentages, as well as the amounts estimated in the rations on succeeding pages, are somewhat smaller than in the older tables.

TOTAL FEED REQUIRED.

A bunch of "feeders" 2 to 3 years old, averaging 1,000 pounds per head and in better than average condition, are to be fattened on clover hay and corn-and-cob meal. Such cattle, if of good grade, should weigh 1,400 pounds each when ready for market and should not require over 200 days to make the gain of 400 pounds. They should therefore make an average gain of 2 pounds per day.

It may be estimated that a gain of 1 pound live weight by animals of this grade will require about 3.5 therms of net energy value in the feed; for a daily gain of 2 pounds, therefore, the requirement would be 7 therms. To this must be added the maintenance requirement, which will increase as the animals grow heavier. For the average weight of 1,200 pounds it is sufficiently accurate to use the maintenance requirement computed in the table on page 14 for 1,250 pounds, viz, 7 therms. This makes the total net energy requirement per day 14 therms on the average of the whole feeding period.

If we assume that 2 pounds of grain will be fed for each pound of hay, it is easy to compute from the figures in the last column of the table on pages 11-13 the amount of feed required to supply 14 therms of net energy, as follows:

	Therms.
In 100 pounds of average clover hay.....	38.68
In 200 pounds of corn-and-cob meal.....	151.60
In 300 pounds of feed.....	190.28
In 1 pound of feed.....	.634

To supply 14 therms requires $14 \div 0.634 = 22.08$ pounds of total feed, consisting of 7.36 pounds of clover hay and 14.72 pounds of corn-and-cob meal, or, in round numbers, $7\frac{1}{2}$ pounds of hay and 15 pounds of meal.

This, of course, represents the average ration for the whole feeding period. At the beginning the feed will naturally be lighter and consist to a larger extent of hay, while the amount of feed, and especially the proportion of grain, will be gradually increased until toward the end of the feeding the animals are consuming all the grain they will take, with only enough hay to insure the necessary bulk and proper digestion. Naturally, too, the form in which the corn is given will usually be varied in the course of the feeding.

IMPROVEMENT OF A RATION.

In the foregoing example it was assumed that the feeding stuffs to be used had been decided upon and attention was directed simply to the quantity required. Let us now take up the question from the other end and see whether a study of the ration may not yield some suggestion of possible improvement.

According to the table on pages 11-13, clover hay and corn-and-cob meal, respectively, contain in 100 pounds—

Feed.	Total dry matter.	Digestible protein.	Net energy value.
	Pounds.	Pounds.	Therms.
Clover hay.....	87.1	4.9	38.68
Corn-and-cob meal.....	89.6	5.7	75.80

The $7\frac{1}{2}$ pounds of clover hay in the ration will evidently contain:

$$87.1 \times 0.075 = 6.53 \text{ pounds of dry matter.}$$

$$4.9 \times 0.075 = 0.37 \text{ pound of digestible protein.}$$

$$38.68 \times 0.075 = 2.90 \text{ therms of net energy value.}$$

A precisely similar computation for the corn-and-cob meal gives the following results:

$$89.6 \times 0.15 = 13.44 \text{ pounds of dry matter.}$$

$$5.7 \times 0.15 = 0.85 \text{ pound of digestible protein.}$$

$$75.8 \times 0.15 = 11.37 \text{ therms of net energy.}$$

Adding these amounts, we find that the total ration contains:

Kind and amount of feed.	Total dry matter.	Digestible protein.	Net energy value.
	Pounds.	Pounds.	Therms.
Clover hay, $7\frac{1}{2}$ pounds.....	6.53	0.37	2.90
Corn-and-cob meal, 15 pounds.....	13.44	.85	11.37
Total.....	19.97	1.22	14.27

The quantity of energy, of course, corresponds with that estimated to be necessary, because the amounts of feed were fixed upon on that basis. We observe, however, that the amount of digestible protein in the ration is less than is estimated on page 16 to be needed by beef cattle of this age. A ration like the above might produce fair gains, but it probably would fail to take full advantage of the capacity of such cattle for growth and the gain would most likely fall below that which was anticipated. An increase in the protein could be expected to make the ration more efficient.

To make any marked change in the ration in this respect, it is evident that we must introduce into it some feed much richer in protein than either of those composing it. On consulting the table it is evident that what we need is one of the by-product feeds like gluten feed or meal, the oil meals, etc., and also that only a small amount of one of these will be needed to effect a marked change in the ration. Thus, if we substitute 2 pounds of old-process linseed meal for 2 pounds of the corn-and-cob meal, the ration will foot up as follows:

Kind and amount of feed.	Total dry matter.	Digestible protein.	Net energy value.
	<i>Pounds.</i>	<i>Pounds.</i>	<i>Therms.</i>
Clover hay, 7½ pounds.....	6.53	0.37	2.90
Corn-and-cob meal, 13 pounds.....	11.65	.74	9.85
Old-process linseed meal, 2 pounds.....	1.82	.57	1.78
Total.....	20.00	1.68	14.53

Thus at a comparatively small additional expense we are able to improve the ration materially by adding the lacking protein, and there is little doubt that the improved ration would produce a more rapid gain and, under ordinary conditions, a more profitable one as well, either by increasing the total gain or shortening the feeding period.

COMPUTING A RATION FROM GIVEN FEEDING STUFFS.

There are available for a dairy herd field-cured corn forage (including the ears), clover hay, corn meal, wheat bran, and gluten feed. The table on pages 11-13 shows that these feeding stuffs, if of good average quality, will furnish in 100 pounds:

Feed.	Total dry matter.	Digestible protein.	Net energy value.
	<i>Pounds.</i>	<i>Pounds.</i>	<i>Therms.</i>
Corn forage.....	81.7	2.3	43.94
Clover hay.....	87.1	4.9	38.68
Corn meal.....	88.7	6.4	88.75
Wheat bran.....	89.9	10.8	53.00
Gluten meal.....	90.9	28.1	84.15

The cows average 850 pounds per head and have produced in previous years an average of 20 pounds of milk per day testing 4 per cent of fat. According to the table on page 14, the maintenance requirement of such animals per day and head would be approximately—

Digestible protein.....	pound..	0.43
Net energy.....	therms..	5.40

For the production of 20 pounds of 4 per cent milk there would be needed, according to the estimates on page 18:

Digestible protein (0.05×20).....	pound..	1.0
Net energy (0.27×20).....	therms..	5.4

The total feed requirements per day and head are therefore:

	Digestible protein.	Net energy value.
	<i>Pounds.</i>	<i>Therms.</i>
For maintenance.....	0.43	5.40
For milk production.....	1.00	5.40
Total.....	1.43	10.80

The problem, then, is to find a mixture of the available feeding stuffs which will yield these amounts of digestible protein and of energy, and which shall have a suitable bulk.

The first step in the construction of a ration is to fix upon the amounts of coarse fodders. It is usually desirable to use as large a proportion of these as possible, since they are usually cheaper sources of food than grain. On the other hand, the amount of them which an animal can consume is limited. Much depends upon the individual animals, and the proper amount can only be told by trial, but we should probably aim to get from 12 to 14 pounds of dry matter in the form of coarse fodder. Corn forage being a cheap feeding stuff, we shall naturally use this freely, with probably some hay for variety. By a little trial, we find that 10 pounds of corn forage and 6 pounds of clover hay will give us 13.4 pounds of dry matter and the amounts of digestible protein and of energy shown below:

Kind and amount of feed.	Total dry matter.	Digestible protein.	Net energy value.
	<i>Pounds.</i>	<i>Pounds.</i>	<i>Therms.</i>
Corn forage, 10 pounds.....	8.17	0.23	4.39
Clover hay, 6 pounds.....	5.23	.29	2.32
Total.....	13.40	.52	6.71

To this we have to add sufficient grain to bring the ration up to the requirement. The proper amount we must ascertain by trial. We will take, at a venture, 4 pounds of corn meal and 2 pounds of wheat bran. Adding this to the ration we have:

Kind and amount of feed.	Total dry matter.	Digestible protein.	Net energy value.
	<i>Pounds.</i>	<i>Pounds.</i>	<i>Therms.</i>
Corn forage, 10 pounds.....	8.17	0.23	4.39
Clover hay, 6 pounds.....	5.23	.29	2.32
Corn meal, 4 pounds.....	3.55	.26	3.55
Wheat bran, 2 pounds.....	1.80	.22	1.06
Total.....	18.75	1.00	11.32

Comparing these totals with the requirement as computed, we find that the ration is ample as regards energy but considerably low in digestible protein. The rather low figure for dry matter shows that more feed may be added to the ration if desirable, but the total for net energy makes it evident that what is needed is not more feed, but feed of a different composition, supplying more protein along with rather less energy. Gluten meal answers this requirement, and substituting 2 pounds of it for 2 pounds of corn meal gives a ration which, while still a trifle high in energy, agrees as closely as necessary with the computed requirements. Thus:

Kind and amount of feed.	Total dry matter.	Digestible protein.	Net-energy value.
	<i>Pounds.</i>	<i>Pounds.</i>	<i>Therms.</i>
Corn forage, 10 pounds.....	8.17	0.23	4.39
Clover hay, 6 pounds.....	5.23	.29	2.32
Corn meal, 2 pounds.....	1.77	.13	1.78
Wheat bran, 2 pounds.....	1.80	.22	1.06
Gluten meal, 2 pounds.....	1.82	.56	1.68
Total.....	18.79	1.43	11.23

This ration corresponds with the average requirement of the whole herd, since it is based on its average performance. It hardly need be said that it should be modified to suit the requirements and capacities of the individual cows, the heavy milkers getting more and the lighter ones less.

By proceeding in this manner, with a little patience we can usually get a ration corresponding as closely as is necessary to the requirement, provided the feeds available admit of it. With a little experience one very soon learns to guess pretty closely, and with some practice the computations become very easy. An exact agreement with the requirement need not be sought for, since in practice the composition of the feeds will probably vary more or less from the average of the tables.

THE CHOICE OF FEEDING STUFFS.

When, as in the last example, feeding stuffs must be purchased in order to get the desired relation between the protein and the energy of the ration, it is evident that often a wide range of choice may be offered. In such a case the question at once arises which of the various feeds available is it most economical to purchase, it being evident of course, that this is not necessarily the one offered at the lowest price.

No simple method of determining this point is possible, because, as we have seen, the feed serves two entirely distinct purposes in the body. Sometimes the supply of protein is the specially important point, and in other cases what is needed is a supply of energy without special reference to whether its source be protein or nonnitrogenous material. Consequently, the relative values of two feeding stuffs may vary under different circumstances. Some writers have based their comparisons of the values of by-product feeds solely upon their content of protein, for the reason that such feeds are often bought especially to supply this ingredient, while the fats and especially the carbohydrates are usually produced in abundance upon the farm. They regard that purchased feeding stuff as the most economical which furnishes a pound of digestible protein at the lowest cost, ignoring any value in the other ingredients. It is obvious, however, that this is a one-sided view. The other ingredients have a value, and this is especially true in the case of a feeder who buys a considerable part of his grain supply and depends upon it as a source of energy as well as of protein. The method of comparison illustrated in the following pages is based primarily upon the cost per unit of energy because this is on the whole the most important function of the feed, but the method takes account also of the amount of protein present.

Let us suppose the following feeding stuffs are available to a dairyman at the prices named:

Prices of feeds per ton.

Oats (40 cents per bushel).....	\$25
Corn meal.....	25
Wheat bran.....	21
Wheat middlings (flour).....	24
Dried brewers' grains.....	23
Gluten meal.....	27
Cottonseed meal (prime).....	30
Old-process linseed meal.....	33

The supply of coarse feed on the farm is sufficient to furnish each animal per day 32 pounds of silage and 8 pounds of clover hay; the cows average 1,000 pounds each and may be expected to produce per day about 24 pounds of milk testing 4.5 per cent fat.

The first step is to compute, in precisely the same way as in the previous example, the estimated requirements of these cows per day as follows:

	Digestible protein.	Net-energy value.
	<i>Pounds.</i>	<i>Therms.</i>
For maintenance.....	0.50	6.00
For 24 pounds of milk:		
Protein 24×0.052	1.25	
Net energy 24×0.29		6.96
Total requirement.....	1.75	12.96

The amount of silage and clover hay available will furnish, according to the table on pages 11-13, the following amounts of dry matter, digestible protein, and net energy value:

Kind and amount of feed.	Total dry matter.	Digestible protein.	Net energy value.
	<i>Pounds.</i>	<i>Pound.</i>	<i>Therms.</i>
Corn silage, 32 pounds.....	8.42	0.19	5.09
Clover hay, 8 pounds.....	6.97	.39	3.09
Total.....	15.39	.58	8.18

The question now is what feeding stuffs is it most economical to buy (or to refrain from selling if in stock) to complete the ration. The first step in deciding this question is to compare the various feeds as sources of energy and see which one furnishes a unit of net energy value at the lowest price. This computation gives the following results:

Kind of feed.	Cost of 100 pounds.	Energy value of 100 pounds.	Cost of 1 therm net energy value.
		<i>Therms.</i>	<i>Cents.</i>
Oats.....	\$1.25	67.56	1.85
Corn meal.....	1.25	88.75	1.41
Wheat bran.....	1.05	53.00	1.98
Wheat middlings.....	1.20	75.02	1.60
Dried brewer's grains.....	1.15	53.38	2.15
Gluten meal.....	1.35	84.15	1.60
Cottonseed meal.....	1.50	90.00	1.67
Old-process linseed meal.....	1.65	88.91	1.86

Evidently, if it were simply a question of supplying energy to the animals, we should use corn meal, since that supplies a unit of energy at a much lower price than any of the other feeding stuffs. If it were thought desirable to add variety to the ration, wheat middlings would obviously be our next choice.

It is evident, however, without going through the labor of computation, that while corn meal and wheat middlings may be used in the ration, neither will supply enough protein if used exclusively. Of the available feeding stuffs which are rich in protein and which may therefore serve to balance the deficiency of this ingredient, gluten meal is relatively the cheapest, and cottonseed meal comes next. While the difference between the two is not great, we shall naturally try the cheaper one. It is not difficult to determine by a few trials that $2\frac{1}{2}$ pounds of corn meal and $3\frac{1}{2}$ pounds of gluten meal, in addition to the coarse fodder available, will give a ration corresponding very closely to the requirements, as the following table shows:

Kind and amount of feed.	Total dry matter.	Digestible protein.	Net energy value.
	<i>Pounds.</i>	<i>Pounds.</i>	<i>Therms.</i>
Corn silage, 32 pounds.....	8.42	0.19	5.09
Clover hay, 8 pounds.....	6.97	.39	3.09
Corn meal, $2\frac{1}{2}$ pounds.....	2.22	.16	2.22
Gluten feed, $3\frac{1}{2}$ pounds.....	3.18	.98	2.95
Total.....	20.79	1.72	13.35

This ration shows as close an agreement with the computed protein requirement as could be desired, but contains a slight surplus of energy. The comparatively low figure for dry matter indicates that more coarse fodder might have been used had it been available, with the probable effect of cheapening the ration. As it is, we have used the feeds relatively lowest in price and apparently have a very economical ration.

Cottonseed meal, however, is nearly as cheap as a source of energy as gluten meal, while it contains considerably more protein. It seems worth while, therefore, to see whether it may not be possible to secure the necessary protein more cheaply by using a smaller amount of the former feed in place of the gluten meal. Three pounds of cottonseed meal will supply almost exactly the same amount of protein as $3\frac{1}{2}$ pounds of gluten meal. Making this substitution, the ration stands as follows:

Kind and amount of feed.	Total dry matter.	Digestible protein.	Net energy value.
	<i>Pounds.</i>	<i>Pounds.</i>	<i>Therms.</i>
Corn silage, 32 pounds.....	8.42	0.19	5.09
Clover hay, 8 pounds.....	6.97	.39	3.09
Corn meal, $2\frac{1}{2}$ pounds.....	2.22	.16	2.22
Cottonseed meal, 3 pounds.....	2.77	.96	2.70
Total.....	20.38	1.70	13.10

This ration agrees with the computed requirements even better than the previous one, while a simple comparison shows that it is actually a trifle cheaper. The grain portion of the two rations costs as follows:

Feed in ration.	First ration.	Second ration.
	<i>Cents.</i>	<i>Cents.</i>
Corn meal.....	3.13	3.13
Gluten meal.....	4.73	
Cottonseed meal.....		4.20
Total.....	7.86	7.33

It thus appears that the ration made up with the somewhat more expensive cottonseed meal is actually the cheaper. The difference, to be sure, is small, yet for 30 cows fed for 200 days it would amount to \$30. Such a difference is only likely to be found, however, when, as was assumed in this instance, some feed very high in protein can be had at a relatively cheap rate. In general, it may be said that when there are no very marked differences in the cost of a therm of energy value in the feeding stuffs constituting the bulk of the ration one of the various high-protein feeds which supplies energy at the lowest cost should ordinarily be used, although it is always wise to check up this point, as in the example just given.

THE COMPOUNDING OF RATIONS.

While in the foregoing examples an exact daily ration is computed, it would, of course, be utterly impracticable in most cases to weigh out separately each day's ration for each animal. Individual weighings of feeds at intervals would often yield valuable information and might be profitably undertaken, but for the ordinary routine of feeding simpler methods must be used.

When practicable, the grain feed may be advantageously mixed in advance in the desired proportions in as large quantities as the storage capacity available and the proper preservation of the materials will permit. Where facilities are available, the whole amount of grain required for all the animals may be weighed out daily, or even for each feeding, without much additional labor. In distributing the grain to the individual animals, regard of course should be paid to their productive capacity and their individual peculiarities. The ration, as computed, is for the average animal. The skill of the feeder is shown in adapting it in quality and in amount to the individual. Doubtless individual weighings at intervals, as already suggested, would be useful as a control on the accuracy of the distribution.

The weighing of coarse fodder is usually a more difficult problem on account of its bulk. When, however, silage or cut fodder is handled in trucks, the matter is still comparatively simple. Long fodder, on the contrary, is not readily weighed. Nevertheless, even here an occasional weighing, if practicable, as a control upon the feeding, is very desirable.

In all these and similar matters common sense is necessary. The computed ration expresses the best estimate that can be made of the actual average requirements, but it is at best more or less of an approximation. It would be foolish, therefore, to seek extreme exactness in realizing it or to go to more expense in the weighing and apportioning of the feed than the saving in the latter would amount to. The scale upon which the feeding is conducted will play an important part. Where scores or hundreds of animals are being fed, an exactness may be profitably sought which would be absurd in the case of two or three animals. Finally, it should be remembered that these computed rations are guides and not recipes. They may aid the feeder in wisely using the resources at his command, but they can not take the place of experience and good judgment.

BEARING ON FARM MANAGEMENT.

The data and the methods of computation on previous pages will aid the feeder in determining the amounts of each class of feeds needed for each class of his animals. The man of good business habits will find them useful in determining the quantities of each kind of feed to grow or purchase and in deciding upon the purchase of animals to feed and the feeds to keep or to purchase for feeding them. These facts and methods will aid the farmer, the feeder, or the user of work animals in deciding upon the chances of profit in proposed enterprises. Often by using these formal ways of checking up a proposed business project the way is made more clear to avoid loss and to secure the largest practicable profit. In case of the farmer who grows most of his feed stuffs, these facts and methods of calculation may often be used in connection with the planning of his scheme of crop rotation and in proportioning the acreages of the respective crops to each other and to the numbers of each class of animals. They will prove useful in reducing the farm-management plan to a scientific basis.

**PUBLICATIONS OF U. S. DEPARTMENT OF AGRICULTURE RELATING TO
FEEDS FOR FARM ANIMALS.**

AVAILABLE FOR FREE DISTRIBUTION BY THE DEPARTMENT.

Emmer: Grain for Semiarid Regions. (Farmers' Bulletin 139.)
Alfalfa. (Farmers' Bulletin 339.)
Soy Beans. (Farmers' Bulletin 372.)
Oats: Growing the Crop. (Farmers' Bulletin 424.)
Winter Oats for the South. (Farmers' Bulletin 436.)
Red Clover. (Farmers' Bulletin 455.)
Winter Emmer. (Farmers' Bulletin 466.)
Sweet Clover. (Farmers' Bulletin 485.)
Market Hay. (Farmers' Bulletin 508.)
Vetch Growing in South Atlantic States. (Farmers' Bulletin 529.)
Kafir as a Grain Crop. (Farmers' Bulletin 552.)
Cottonseed Meal for Feeding Beef Cattle. (Farmers' Bulletin 655.)
Uses of Sorghum Grain. (Farmers' Bulletin 686.)
Feeding of Grain Sorghums to Live Stock. (Farmers' Bulletin 724.)
Natal Grass: A Southern Perennial Hay Crop. (Farmers' Bulletin 726.)
The Feeding of Dairy Cows. (Farmers' Bulletin 743.)
Feeding and Management of Dairy Calves and Young Dairy Stock. (Farmers' Bulletin 777.)

**FOR SALE BY THE SUPERINTENDENT OF DOCUMENTS, GOVERNMENT PRINTING
OFFICE, WASHINGTON, D. C.**

Influence of Type and of Age upon Utilization of Feed by Cattle. (Bureau of Animal Industry, Bulletin 128.) Price, 30 cents.
Nutritive Value of Nonprotein of Feeding Stuffs. (Bureau of Animal Industry, Bulletin 139.) Price, 10 cents.
Maintenance Rations of Farm Animals. (Bureau of Animal Industry, Bulletin 143.) Price, 15 cents.
Feeding Beef Cattle in Alabama. (Bureau of Animal Industry, Bulletin 159.) Price, 10 cents.
Feeding Value of Cereals, as Calculated from Chemical Analyses. (Bureau of Chemistry, Bulletin 120.) Price, 10 cents.
Making and Feeding Silage. (Farmers' Bulletin 578.) Price, 5 cents.

ADDITIONAL COPIES
OF THIS PUBLICATION MAY BE PROCURED FROM
THE SUPERINTENDENT OF DOCUMENTS
GOVERNMENT PRINTING OFFICE
WASHINGTON, D. C.
AT
5 CENTS PER COPY
▽

Weak Places in the Methods Used in Animal Nutrition Investigations

By J. AUGUST FRIES
The Institute of Animal Nutrition, The Pennsylvania
State College

REPRINTED FROM THE
PROCEEDINGS OF THE AMERICAN SOCIETY
OF ANIMAL PRODUCTION, 1916

WEAK PLACES IN THE METHODS USED IN ANIMAL NUTRITION INVESTIGATIONS

By J. AUGUST FRIES

The Institute of Animal Nutrition, The Pennsylvania State College

The old adage, "a chain is no stronger than its weakest link" is to a large extent at least, applicable to investigations in that their results are no better than the weakest part of the methods employed.

Should it be known, however, that there is a certain percentage of possible error in some one of the processes or methods used in an experiment, it certainly should be no argument for only carrying the rest of the methods to that same degree of accuracy, as is frequently claimed.

In any elaborately planned comprehensive scientific investigation the work should always be done as accurately as the best available methods ordinarily permit, for the reason, if for no other, that the accumulated analytical and other data can be worked over and used for side studies which would not be influenced by an error in some one or more steps of the investigation as a whole.

On the other hand with less elaborate experiments, where only a certain main fact is aimed at, and the work is not comprehensive enough to promise any extra later development, it would be foolish to waste much extra time and money to reach a degree of accuracy of say 0.05 per cent in one place when there are known to be defects elsewhere in the methods allowing 2-4 per cent of uncertainty.

In connection with this topic we shall not discuss the very important human element, as the skill, thoroughness, honesty and good judgment of the individual who has a hand in the work, and which enters so largely into a successful investigation, nor the ordinary methods of chemical analysis and extent of analytical errors allowed. We shall only call attention to some of the things which are frequently allowed to slip by without much serious thought, partly perhaps because of their very bulkiness and bigness.

Length of Digestion Experiment

The author has sometimes been asked "how many days should digestion experiments with cattle last?" This question in other words means; how many days are necessary for the collection of the excreta to insure a reliable daily average of the same?

An answer to that question depends upon the degree of accuracy sought for in the experiment, as well as the time and money available for the work. Instead, therefore, of giving a definite answer that could

not cover all cases, I shall answer it by giving the results of some observations and statistics from which anyone may draw his own conclusions and answer to suit his own case. These figures will show the irregularity as to time and quantity of the voidings of the daily excreta.

In 1908 the author made some observations on a steer, noting the time and quantity of each voiding of feces and urine during several days. It was during one of our regular digestion experiments No. 208, Periods V and VI, with a young Hereford steer, weighing about 280 kilograms. During Period V his daily ration was 3.60 kgs. and during Period VI, 2.40 kgs. alfalfa hay. The time of observation was, in Period V, from March 10th, 9:20 and 11:10 A. M., to March 12th, 6 P. M., and in Period VI, from March 31st, 1:02 and 1:58 P. M., to April 2nd, 6 P. M., and the summary of the observations is given in the following table:

Table I. Frequency and weight of voidings of feces and urine by a steer and variations in daily total excreta

Experiment No. 208, Steer C, 1908	Period V		Period VI	
	Feces	Urine	Feces	Urine
Number of voidings in 56½ and 55, 53 and 52 hours, respectively	23	23	18	16
Longest interval in minutes.....	340	245	380	435
Shortest interval in minutes.....	15	55	15	55
Largest weight in grams.....	960	1190	840	870
Smallest weight in grams.....	90	145	90	160
Total excreta for last 24 hours, grams...	6140	5415	4510	3810
Total excreta for previous 24 hrs., grams.	6100	5380	3410	3275
Daily average for 10 days, grams.....	6224	4817.5	4345	3890
Highest in 10 days, grams.....	6950	6210	5750	6385
Lowest in 10 days, grams.....	5400	4005	3705	3140

These results show a very great irregularity in regard to time between voidings as well as to weights. Further, it was noticed that there is absolutely no relation between time and quantity, since after a short period of time often a large amount was voided, and after long periods, only small amounts.

Possible Uncertainty in the Total Excreta of the 10-Day Periods

Should, as we may conceive possible, two of the largest voidings just fail to come within the period at the beginning and ending, the total for the ten days would be affected to the following extent:

	Feces Per ct.	Urine Per ct.
Period V	3.08	4.94
Period VI	3.86	4.47

Assuming that in the 10-day period the highest daily quantity obtained was replaced by the smallest, the difference in the daily average due to that interchange alone would be:

	Feces Per ct.	Urine Per ct.	Urine nitrogen Per ct.
Period V	2.49	4.58	1.59
Period VI	4.70	8.34	2.41

Thus the possibilities may be multiplied but since the nitrogen in the urine does not vary corresponding to the weight of urine, and the daily feces may vary somewhat in dry matter, it is desirable to study rather the variation in the dry matter and nitrogen.

In digestion work with cattle it is customary to have the periods of not over ten days, during which time daily aliquots are taken of the excreta and composited into samples for chemical analyses.

A number of such 10-day periods will give a fair idea of the irregularities which may be expected in the daily excretion. Many combinations of days within the periods could be studied and compared, but in the following we shall only note what the results would be in a number of such feeding periods, should we for one reason or another have to use the first nine days, the last nine, the first eight, the last eight or the middle eight days of the ten for the composite samples upon which to base the results of the experiments.

The following tables give the average daily dry matter of feces and average daily nitrogen of urine for ten, nine, and eight days of twenty-two such 10-day periods, as compared with the amounts computed from the composite sample for the ten days and also the percentage variations of the results obtained from the dailies, from those of the composite samples.

Table II. Average daily dry matter of feces during 8, 9, and 10 days of the digestion periods

Experiment number and period	Com-puted from 10 days compo-site sample Grams	Computed from daily samples of					Percentage difference between the various groups of days and the 10-day composite						
		10 days Grams	First 9 days Grams	Last 9 days Grams	First 8 days Grams	Last 8 days Grams	Middle 8 days Grams	10 days %	First 9 days %	Last 9 days %	First 8 days %	Last 8 days %	Middle 8 days %
212, I.....	2663.3	2664.8	2650.0	2658.1	2616.7	2667.4	2640.6	+ .06	- .50	- .17	- 1.75	+ .16	- .85
212, II.....	2786.9	2749.2	2726.8	2723.9	2761.7	2695.2	2695.5	- 1.35	- 2.16	- 2.26	- .91	- 3.29	- 3.28
212, III.....	2104.8	2076.5	2039.7	2047.7	2029.4	2034.5	2002.8	- 1.35	- 3.09	- 2.71	- 3.58	- 3.34	- 4.85
212, IV.....	2280.5	2262.6	2278.2	2230.5	2297.6	2214.3	2244.0	- .79	- .10	- 2.19	- .75	- 2.90	- 1.60
212, V.....	1108.5	1194.4	1185.7	1193.1	1164.6	1226.5	1183.0	+ 7.74	+ 6.96	+ 7.63	+ 5.06	+ 10.64	+ 6.72
212, VI.....	1221.3	1278.1	1280.5	1302.5	1276.4	1298.2	1290.2	+ 4.65	+ 4.85	+ 6.65	+ 4.51	+ 6.30	+ 5.64
216, I.....	2746.8	2673.2	2672.7	2692.2	2637.0	2670.5	2694.0	- 2.68	- 2.70	- 1.99	- 4.00	- 2.78	- 1.92
216, II.....	1120.6	1152.3	1155.6	1160.3	1160.0	1174.7	1152.6	+ 3.72	+ 3.12	+ 3.54	+ 3.51	+ 4.82	+ 2.85
216, III.....	1710.0	1647.8	1630.2	1647.0	1617.7	1645.5	1627.1	- 3.64	- 4.67	- 3.68	- 5.44	- 3.77	- 4.85
216, IV.....	728.9	727.9	719.5	764.7	723.9	699.9	692.2	- .14	- 1.29	+ 4.91	- .69	- 3.98	- 5.04
216, V.....	3297.6	3281.5	3261.6	3288.4	3299.9	3261.0	3266.8	- .49	- 1.09	- .28	+ .07	- 1.11	- .93
216, VI.....	2482.4	2467.8	2468.5	2485.3	2466.8	2485.1	2488.3	- .59	- .56	+ .12	- .63	+ .11	+ .24
216, VII.....	1384.2	1391.8	1398.3	1394.8	1401.5	1384.0	1402.1	+ .55	+ 1.02	+ .77	+ 1.25	- .02	+ 1.29
217, I.....	1054.5	1045.0	1047.4	1055.7	1063.1	1069.6	1059.9	- .90	- .68	+ .11	+ .81	+ 1.43	+ .51
217, II.....	2358.7	2295.4	2266.3	2313.7	2248.3	2291.0	2283.3	- 2.69	- 3.92	- 1.91	- 4.68	- 2.87	- 3.20
217, III.....	2497.4	2439.9	2372.5	2469.7	2420.2	2479.4	2397.6	- 2.30	- 5.00	- 1.11	- 3.09	- .72	- 4.00
217, IV.....	1215.4	1149.1	1115.1	1173.5	1121.4	1170.6	1138.4	- 5.47	- 8.25	- 3.45	- 7.73	- 3.69	- 6.34
220, I.....	2619.5	2573.7	2545.7	2565.0	2557.0	2544.0	2532.4	- 1.75	- 2.82	- 2.08	- 2.39	- 2.89	- 3.32
220, II.....	1604.8	1603.9	1596.8	1621.1	1573.9	1626.4	1615.3	- .06	- .50	+ 1.01	- 1.93	+ 1.34	+ .65
220, III.....	834.4	805.1	784.0	810.5	742.0	807.5	787.3	- 3.51	- 6.04	- 2.87	- 11.07	- 3.32	- 5.65
220, IV.....	1777.1	1729.0	1695.2	1749.2	1652.7	1758.2	1713.7	- 2.71	- 4.61	- 1.57	- 7.00	- 1.06	- 3.57
220, V.....	552.4	541.7	562.7	538.0	559.0	536.3	548.7	- 1.94	+ 1.86	- 2.61	+ 1.19	- 2.92	- 0.67

Table III. Average daily nitrogen during 8, 9, and 10 days of the digestion period

Experiment number and period	Com-puted from 10 days compo-site sample (Grams)	Computed from daily samples of					Percentage difference between the various groups of days and the 10-day composite						
		10 days (Grams)	First 9 days Grams	Last 9 days Grams	First 8 days Grams	Last 8 days Grams	Middle 8 days Grams	10 days %	First 9 days %	Last 9 days %	First 8 days %	Last 8 days %	Middle 8 days %
212, I.....	113.44	115.27	114.48	115.92	113.23	115.92	115.12	+ 1.61	+ .92	+ 2.19	- .19	+ 2.19	+ 1.48
212, II.....	107.63	107.11	107.41	106.87	107.48	106.43	107.18	- .48	- .21	- .71	- .14	- 1.12	- .42
212, III.....	94.47	93.72	92.99	92.75	92.55	92.83	91.81	- .79	- 1.57	- 1.82	- 2.03	- 1.74	- 2.82
212, IV.....	89.02	90.69	90.77	90.31	91.76	89.41	90.36	+ 1.88	+ 1.97	+ 1.45	+ 3.08	+ .44	+ 1.50
212, V.....	66.58	65.33	65.25	64.88	65.36	64.05	64.72	- 1.88	- 2.00	- 2.55	- 1.83	- 3.80	- 2.79
212, VI.....	61.13	58.25	58.40	57.97	57.65	57.92	58.11	- 4.71	- 4.47	- 5.17	- 5.69	- 5.25	- 4.94
216, I.....	65.81	66.78	66.10	66.52	63.60	68.89	66.23	+ 1.47	+ .44	+ 1.09	- 3.36	+ 4.68	+ .64
216, II.....	42.71	43.12	43.58	43.18	43.73	42.94	43.82	+ .96	+ 2.04	+ 1.10	+ 2.39	+ .54	+ 2.60
216, III.....	49.37	49.75	49.73	50.76	48.84	50.06	50.85	+ .77	+ .73	+ 2.81	- 1.07	+ 1.40	+ 3.00
216, IV.....	35.07	35.11	35.10	35.53	34.86	35.46	35.57	+ .11	+ .09	+ 1.31	- .60	+ 1.11	+ 1.43
216, V.....	127.30	129.67	130.14	129.36	130.46	130.37	129.85	+ 1.86	+ 2.23	+ 1.62	+ 2.48	+ 2.80	+ 2.00
216, VI.....	100.56	100.90	99.88	99.75	99.43	98.66	98.46	+ .34	- .68	- .81	- 1.12	- 1.89	- 2.09
216, VII.....	70.22	70.52	71.04	71.03	71.90	70.36	71.67	+ .43	+ 1.17	+ 1.15	+ 2.39	+ .48	+ 2.06
217, I.....	79.11	79.47	78.90	79.03	83.37	78.10	78.35	+ .45	- .27	- .10	+ 5.39	- 1.28	- .96
217, II.....	136.37	139.42	139.15	138.80	138.53	139.14	138.46	+ 2.24	+ 2.04	+ 1.78	+ 1.58	+ 2.03	+ 1.53
217, III.....	141.93	142.60	144.55	140.16	148.79	140.28	142.06	+ .47	+ 1.85	- 1.25	+ 4.83	- 1.16	+ .09
217, IV.....	106.69	106.96	107.66	106.73	108.31	106.36	107.49	+ .25	+ .91	+ .04	+ 1.52	- .31	+ .75
220, I.....	44.44	43.96	44.00	44.16	43.36	44.57	44.23	- 1.08	- .99	- .63	- 2.43	+ .29	- .47
220, II.....	36.46	35.92	35.92	36.19	36.04	35.90	35.97	- 1.47	- 1.47	- .74	- 1.15	- 1.54	- 1.34
220, III.....	33.61	33.13	33.77	33.07	33.91	33.01	33.78	+ .48	+ .48	- 1.61	+ .89	- 1.79	+ .51
220, IV.....	37.11	37.91	37.92	38.68	38.08	38.52	38.78	+ 2.15	+ 2.18	+ 4.23	+ 2.61	+ 3.80	+ 4.50
220, V.....	36.34	36.24	36.29	35.43	36.23	34.91	35.39	- .28	- .14	- 2.51	- .30	- 3.94	- 2.61

A glance at these tables shows a considerable variation between the average per day for eight, nine, and ten days of a period, as well as between the composite sample results and the averages obtained from the daily samples. In case of the dry matter in the feces the results range from +10.64 per cent to -11.07 per cent and for the average daily nitrogen in urine from +5.39 per cent to -5.69 per cent. In one period the average daily dry matter of feces for eight and for nine days differed by 9.48 per cent and in another period by 8.45 per cent. Between two different groups of eight days of the ten, there was in one case a difference of 8.82 per cent, and in another 5.32 per cent.

In studying the quantities of dry matter collected each twenty-four hours during the different periods it was noticed that at times one day would have over 100 per cent more dry fecal matter than another.

The following Table IV gives some of the largest differences found between any two days:

Table IV. Largest variations in daily dry matter of feces

Experiment	Period	Dry matter found		Difference Per ct.
		Lowest Grams	Highest Grams	
212	II	1676.6	3591.4	114.2
212	III	1248.4	2522.2	102.0
216	IV	474.1	937.4	97.7
217	III	1991.5	3046.3	53.0
220	III	523.8	1119.6	117.5
220	V	352.6	677.5	92.1

In the urine there was a difference of 5.80 per cent between the average daily nitrogen of eight and nine days in one period, and in one case between two 8-day sections in the same period there was a difference of 7.68 per cent in the average daily nitrogen.

Animals, therefore, that are very irregular in their habits are not the best animals for experimental purposes.

Theoretically, there should be no difference between the composite sample results and the average of the ten daily samples, but considerable differences were observed.

Barring analytical errors, which could not have been large, these differences can only be due to faulty composites, or more likely to unavoidable changes in moisture content of the samples, which important point will be referred to later.

The differences found for dry matter in feces in experiment No. 212, Period V, for example, cause considerable uncertainty in the final results. Referring to these results we make use of the term apparent digestible and metabolizable matter because of uncertain factors. In Computation I, apparent digestible matter = total feed

minus feces, and apparent metabolizable matter = total feed minus feces, urine and methane. In Computation II, the apparent digestible matter = total feed minus feces and methane, and apparent metabolizable matter = total feed minus feces, methane, urine, daily hair and dandruff. The methane in this latter case is considered as unused feed and classed with the feces, and the daily hair and dandruff as body excretions and classed with the urine. The uncertain factor chiefly in mind is the ferment activity in the digestive tract.

Table V. Comparisons of results computed from the composite and average of daily samples. Experiment 212, Period V

	Computation I		Computation II	
	Composite Per ct.	Average of dailies Per ct.	Composite Per ct.	Average of dailies Per ct.
Apparent digestible matter	62.79	59.91	56.02	53.14
Apparent metabolizable matter	49.44	46.56	49.00	46.10

According to the above figures the uncertainty in this case in the final results is nearly three per cent, which is a considerable error, and the larger these uncertainties are, the more frequently the whole experiment must be repeated to obtain reliable average results. From the foregoing, estimates could also be made as to the influence upon the final results of lengthening the digestion period.

Scales

Since the live weight of cattle is not of such great importance in digestion and metabolism experiments, and cattle scales can be readily obtained weighing to 1/10 kilogram, we need not speak of them.

A question frequently asked is "To what degree of accuracy should the daily feed be weighed out?" This question needs to be discussed. Spring balances weighing to within one or two ounces are not suitable or delicate enough for weighing out feed for digestion experiments. For weighing bulky material, the platform scales of the so-called silk scale type, are no doubt the most convenient, and most frequently used. It is possible on these to have divisions of five grams on the beam, but on the larger ones, which will perhaps stand more hard usage, ten gram divisions may be considered the minimum. Taking for granted that the scales are protected from drafts, then if used on a submaintenance ration where less than a kilogram has to be weighed out, there may be a difference or error in weighing of from ten to nearly twenty grams, as weighings are ordinarily done, that is, an error in the feed introduced, equal to one to two per cent. Should spills and refused matter be weighed back on the same scales the errors can thereby be increased. In a ten days' period twenty feeds would undoubtedly

bring the average error down considerably. Yet if we expect to do work of great accuracy the feed should be weighed closer than to within one or two per cent, and this can be done even on this kind of scales by giving more time and more special care to the weighing than is customary.

Sampling of Feed for Analysis

Concentrates and other finely pulverized materials which can readily be mixed present no difficulty in sampling. With coarse fodders such as hay, stover, etc., it is different, and the care and personal good judgment of the one doing the sampling determines largely the degree of correctness of the sample. This refers in particular to getting the right proportion of fine and coarse material represented in the sample and feed ration. Coarse feed should always be cut and reduced to such fineness that it does not tangle or adhere in large bunches, but readily falls apart, before the attempt is made to weigh out the daily rations.

From a well mixed pile of feed, representing approximately the amount to be used, daily feeds are weighed out in suitable receptacles for as many days as practicable. As each day's feed is weighed out a representative portion is set aside for the sample. As large a sample as may conveniently be handled should be taken of bulky feed, that is, the coarser the feed, the larger the sample. On the same day on which it is taken, this sample is cut or ground finer before it is reduced in size, and this process is repeated until the desired bulk and fineness for air drying has been reached, if that is the method employed in preparation of the sample.

The most difficult problem, as well as the hardest to control, is the moisture content of the feed. Roughage is of necessity kept stored in large bulk, usually in places away from where the weighing, sampling, and preparing of samples takes place, and hence, especially under unsettled weather conditions, change in moisture content readily occurs. Care must, therefore, be taken not to expose the feed sample to great variations in temperature, as, for instance, doing part of the work in a room below freezing and part in a warm and relatively damper or drier laboratory.

Composite Samples of Excreta

From the daily excreta, which should be weighed to an accuracy of within a fraction of one per cent, definite proportions are weighed out for the composite samples. These smaller portions must be weighed on balances weighing to 0.1 gram, so that if fifty grams, for instance, is the amount, the error should not be over 0.2 per cent.

Like the feed, the composite feces are air dried before final grinding for analyses.

This final grinding and preparation is no doubt the weakest and most uncertain point in the whole method. The air-dry samples should have acquired the moisture condition corresponding to the atmospheric conditions at the time of weighing and grinding, but the hard, coarse and lumpy air-dry material does not acquire the moisture conditions very quickly, and in changeable weather a sufficient change in the hygroscopic moisture of the fine, and then very hygroscopic material, may take place during grinding to affect the results very decidedly. This in some cases may be the explanation for the very large differences found between the dry matter when computed according to the composite and the average of the ten dailies.

Below is given the loss on air drying and hygroscopic moisture in the composite samples and the average for each ten days in Experiment No. 212. Note especially the difference in hygroscopic moisture in Period V. In Table V it has already been shown how much this difference influenced the final results:

Table VI. Loss on air drying and hygroscopic moisture in the composite samples of feces, also the average moistures of the ten daily samples of each period. Exp. 212

Experiment 212 Period	Composite H ₂ O		Ten dailies Average H ₂ O	
	Loss on air drying Per ct.	Hygroscopic Per ct.	Loss on air drying Per ct.	Hygroscopic Per ct.
I	80.17	4.174	80.03	4.328
II	83.32	5.929	83.87	3.309
III	81.31	4.088	81.39	3.548
IV	79.04	6.762	79.69	4.266
V	77.44	15.700	78.12	6.059
VI	77.84	7.140	76.76	7.111

That great care must be exercised in making up and preparing the composite samples is seen from the above, and the only way to overcome, to a large extent at least, these difficulties with the moisture would be to take a large portion of the coarse fodder sample immediately after weighing out the rations, or of the composite dung sample, and dry completely in a vacuum dryer. No such dryer for large samples having been available this point has not been tested.

Hair and Dandruff

These substances are rich in nitrogen and energy, and inasmuch as the dry matter in these substances is past the point where it can be of any further use in the body metabolism it may be classed with that of urine as an excretum, and should be accounted for. The

daily production and of these substances will vary greatly with the condition of the animal, and the fact that they will influence the end results at times very materially, may be seen from the following example:

Table VII. Comparison of nitrogen and energy in daily hair and dandruff with the total nitrogen in urine and total daily metabolism

	Nitrogen	Energy
Daily urine	42.71 grams	
Total daily metabolism		6986.07 Cals.
Brushings, hair and dandruff	2.179 grams	85.99 Cals.
Hair	.331 grams	11.98 Cals.
Hair and dandruff in per cent of total.....	5.87%	1.40%

ENERGY VALUES OF HOMINY FEED AND MAIZE MEAL FOR CATTLE

By HENRY PRENTISS ARMSBY, *Director*, and J. AUGUST FRIES, *Assistant Director*,
Institute of Animal Nutrition of The Pennsylvania State College

COOPERATIVE INVESTIGATIONS BETWEEN THE INSTITUTE OF ANIMAL NUTRITION OF
THE PENNSYLVANIA STATE COLLEGE AND THE BUREAU OF ANIMAL INDUSTRY OF
THE UNITED STATES DEPARTMENT OF AGRICULTURE

INTRODUCTION

Hominy feed is a by-product of the milling of maize (*Zea mays*) for the production of hominy. In the winter of 1909-10 a series of 10 respiration calorimeter tests was carried out at the Institute of Animal Nutrition for the purpose of determining, by the methods outlined in a previous paper (2),¹ the net energy value of this by-product as compared with that of the maize from which it is manufactured. Some of the data obtained, together with earlier results on maize meal, were included with others in the general discussion of net energy values contained in the paper just referred to, but a review of these results and a more specific comparison of maize with its by-product, hominy feed, or hominy chop, including some more recent results on maize meal (3) seem desirable.

THE FEEDING STUFFS

As stated, hominy feed is a by-product of the manufacture of hominy or brewers' grits. In addition to their use as food, these products are used somewhat extensively by brewers and bakers. They are intended to consist substantially of the endosperm of the maize from which the hulls and germs have been completely separated. It is desired to reduce their percentage of fat to the minimum, and for this reason maize low in fat is preferred and special stress is laid upon the complete separation of the germ. White corn is used exclusively. It is first moistened to loosen the hull and then is passed through a machine called a "degerminator," which cracks the grains and is intended to remove the hulls and germs. The first separation, however, is incomplete, and from this point the material undergoes a process of gradual reduction and separation similar in its general outline to that used in the milling of wheat.

A comparison of the composition of our hominy feed,² as shown by analyses of two independent samples, with that of the hominy feed used

¹ Reference is made by number to "Literature cited," p. 613.

² Through the courtesy of the Miner-Hillard Milling Co., of Wilkes-Barre, Pa., we were able to obtain for experimental purposes a quantity of the freshly manufactured hominy feed and also of the maize from which it was made, and likewise to secure data as to the yield of the various products of the milling.

by Lindsey (6, 7) in the digestion experiments hereafter referred to, and with Henry and Morrison's average of the composition of 778 samples (5, p. 633), is contained in Table I, from which it appears that our hominy feed was of normal composition.

TABLE I.—Percentage composition of hominy feed, water-free

Constituent.	Our analyses.	Lindsey's analyses.		Henry and Morrison's average.
		1904 and 1905.	1907.	
Ash.....	2.75	3.38	2.78	2.9
Protein ^a	9.33	b 12.23	b 11.59	b 11.8
Nonprotein ^c	1.29			
Crude fiber.....	5.13	4.97	5.28	4.9
Nitrogen-free extract.....	72.65	69.43	71.54	71.5
Ether extract.....	8.85	9.99	8.81	8.9
Total nitrogen.....	100.00	100.00	100.00	100.0
Carbon.....	1.83			
Heat of combustion per kilogram, Calories.....	47.31			
	4,709			

^a Protein N×6.0.^b Total N×6.25.^c Nonprotein N×4.7.

The composition of the maize meal employed in this experiment (designated as experiment 211) and of that used in other experiments here, and likewise Henry and Morrison's average of 5,335 analyses (5, p. 633), is shown in Table II.

TABLE II.—Percentage composition of maize meal, water-free

Constituent.	Our experiments.			Henry and Morrison's average.
	Experiment 179.	Experiment 211.	Experiment 220.	
Ash.....	1.37	1.62	1.40	1.47
Protein ^a	9.94	9.29	9.78	c 10.48
Nonprotein ^b	0.48	0.24	0.28	
Crude fiber.....	2.60	3.16	2.04	2.59
Nitrogen-free extract.....	81.38	80.64	82.17	81.18
Ether extract.....	4.23	5.05	4.33	4.28
Total nitrogen.....	100.00	100.00	100.00	100.00
Carbon.....	1.758	1.60	1.689	
Heat of combustion per kilogram, Calories.....	45.03	46.80	46.16	
	4,431	4,517	4,505	

^a Protein N×6.0.^b Nonprotein N×4.7.^c Total N×6.25.

The hay used in our experiments was mixed clover and timothy. In view of the rather low percentage of protein in the concentrates, a legume hay would probly have been preferable, had one been available. The

average composition of eight independent samples of the hay was as shown in Table III.

TABLE III.—Percentage composition of mixed hay, water-free

Constituent.	Composition.
Ash.....	7.01
Protein ^a	9.62
Nonprotein ^b	1.29
Crude fiber.....	33.78
Nitrogen-free extract.....	46.00
Ether extract.....	2.30
Heat of combustion per kilogram.. Calories..	100.00
	4,396

^a Protein N×6.25.^b Nonprotein N×4.7.

PARTITION OF INGREDIENTS OF MAIZE

From a bushel (56 pounds) of maize there are obtained about 38 pounds of hominy, or grits, and about 18 pounds of by-products, consisting of—

- (a) The hulls of the grains, together with the tips, derived from the cob.....about 2 pounds.
- (b) The germs.....about 9 pounds.
- (c) The starch immediately surrounding the germ and tip, which is necessarily scoured off in the various processes of grinding and screening.....about 7 pounds

These three products ground together constitute hominy feed. The percentages of the various products, therefore, are approximately—

Hominy.....	67.9
Hulls and tips.....	3.5
Germs.....	16.1
Scourings.....	12.5
	32.1
	100.0

Partial analyses of samples of the hulls and tips, the germs, and the hominy were also made, with the results shown in Table IV.

TABLE IV.—Percentage composition of milling products

Product.	Total dry matter.	In dry matter.		
		Ash.	Nitrogen.	Carbon.
Hominy.....	86.60	0.50	1.46	45.03
Hulls and tips.....	91.42	1.92	1.41	47.81
Germs.....	91.02	5.95	2.49	50.60

From the foregoing figures the partition of the ingredients and of the energy of 100 pounds of maize between the several products of the milling may be computed to have been as shown in Tables V and VI. The outstanding differences are the considerable proportion of the nitrogen and the large proportion of the ash of the maize found in the hominy feed.

TABLE V.—Partition of ingredients of 100 kgm. of maize

Constituent.	Dry matter.	Ash.	Nitrogen.	Carbon.	Energy.
	Kgm.	Kgm.	Kgm.	Kgm.	Therms.
In 3.5 kgm. of hulls and tips..	3.20	0.06	0.04	1.53	.....
In 16.1 kgm. of germs.....	14.65	.87	.36	7.41	.....
In 12.5 kgm. of scourings....	8.30	.16	.11	4.34	.....
In 32.1 kgm. of hominy feed..	26.15	1.09	.51	13.28	123.14
In 67.9 kgm. of hominy.....	58.80	.29	.86	26.48	a 260.58
In 100 kgm. of maize.....	84.95	1.38	1.37	39.76	383.72

a By difference.

TABLE VI.—Percentage partition of each ingredient

Constituent.	Dry matter.	Ash.	Nitrogen.	Carbon.	Energy.
Hulls and tips.....	3.77	4.35	2.92	3.85	.....
Germs.....	17.25	63.04	26.28	18.64	.....
Scourings.....	9.77	11.59	8.03	10.91	.....
Hominy feed.....	30.79	78.98	37.23	33.40	32.09
Grits.....	69.21	21.02	62.77	66.60	67.91
Maize.....	100.00	100.00	100.00	100.00	100.00

ANIMALS

The experiments were made upon two steers. It was not found practicable to make the comparison on the same animal, since the experiment had other objects, but the two steers were of like breed and very similar in type, steer D being a grade Hereford, 33 months old, and steer G a full-blood Hereford, 38 months old.

GENERAL PLAN

Each animal received three different amounts of hay in as many periods, and from the data thus obtained the energy values of the hay were computed. In two additional periods steer D received a mixed ration of equal parts of hominy feed and mixed hay, and steer G a mixed ration of 1 part mixed hay and 2 parts maize meal. One of these two rations in each case was intended to be approximately a maintenance ration, while the other was as heavy a ration as it was found practicable

to feed. The results upon the concentrates were computed upon the assumption of unchanged utilization of the hay as computed from the three periods on hay alone.

Each period comprised 21 days, of which 11 were regarded as preliminary, while the visible excreta were collected quantitatively for the remaining 10. The complete balance of matter and energy was determined with the respiration calorimeter on the eighteenth and nineteenth days of each period. A list of the periods and rations fed and of the average live weights of the animals is contained in Table VII.

TABLE VII.—Periods, rations, and live weights of experimental animals

Period No.	Preliminary feeding.	Excreta collected.	Rations.			Average live weights.
			Mixed hay.	Hominy feed.	Maize meal.	
Steer D:	1909.	Dec. 30, 1909—Jan. 8, 1910.	Kgm.	Kgm.	Kgm.	Kgm.
Period 1...	Dec. 19-29.....	Dec. 30, 1909—Jan. 8, 1910.	7.0	.....	.....	460
	1910.	1910.				
Period 2...	Jan. 9-19.....	Jan. 20-29.....	2.0	2.0	.....	432
Transition feeding.	Jan. 30-Feb. 5....	.....	.....	.....	.....	.....
Period 3...	Feb. 6-16.....	Feb. 17-26.....	4.5	4.5	.....	470
Transition feeding.	Feb. 27-Mar. 5....	.....	.....	.....	.....	.....
Period 4...	Mar. 6-16.....	Mar. 17-26.....	4.0	.....	.....	455
Period 5...	Mar. 27-Apr. 6....	Apr. 7-16.....	2.0	.....	.....	428
Steer G:	1910.	1910.				
Period 1...	Jan. 2-12.....	Jan. 13-22.....	7.0	.....	.....	389
Period 2...	Jan. 23-Feb. 2....	Feb. 3-12.....	.9	.....	1.8	358
Transition feeding.	Feb. 13-19.....	.....	.....	.....	.....	.....
Period 3...	Feb. 20-Mar. 2....	Mar. 3-12.....	2.7	.....	5.4	398
Transition feeding.	Mar. 13-19.....	.....	.....	.....	.....	.....
Period 4...	Mar. 20-30.....	Mar. 31-Apr. 9....	3.6	.....	.....	387
Period 5...	Apr. 10-20.....	Apr. 21-30.....	1.8	.....	.....	364

PERCENTAGE DIGESTIBILITY

The digestibility of the total rations and that of the grain as computed on the assumption that the hay consumed with it had the digestibility shown by the true average of the periods on hay alone was as shown in Table VIII.

TABLE VIII.—Percentage digestibility of rations and of grain

Animal and constituent.	Hay.				Mixed hay and grain.		Computed digestibility of grain.	
	Period 1.	Period 4.	Period 5.	Average.	Period 2.	Period 3.	Period 2.	Period 3.
Steer D (hominy feed):								
Dry matter.....	55.96	60.58	58.23	57.72	72.71	72.42	87.56	86.98
Ash.....	40.79	34.72	37.77	38.58	30.79	43.42	11.09	56.38
Organic matter.....	57.09	62.32	59.72	59.10	74.89	73.97	89.83	87.98
Protein.....	44.38	59.29	58.50	48.10	55.73	59.01	63.04	71.64
Crude fiber.....	52.09	59.31	55.21	54.76	61.09	54.92	101.94	55.94
Nitrogen-free extract.....	62.96	66.57	65.79	64.52	81.40	80.93	91.97	91.10
Ether extract.....	56.38	56.90	56.94	56.65	88.50	87.27	96.47	95.36
Total nitrogen.....	49.10	53.35	49.96	50.54	58.54	64.06	66.25	77.98
Carbon.....	52.98	58.52	56.32	55.18	72.65	71.91	89.33	88.03
Energy.....	52.80	58.17	55.43	54.84	72.35	71.60	88.52	87.17
Steer G (maize meal):								
Dry matter.....	59.23	60.06	59.02	59.44	80.72	72.73	91.63	79.55
Ash.....	51.44	37.05	34.25	45.13	27.23	36.22	11.90	15.89
Organic matter.....	60.54	61.60	60.82	60.89	82.62	74.06	93.16	80.45
Protein.....	48.56	50.72	37.27	47.76	63.22	55.57	71.06	59.95
Crude fiber.....	56.91	59.36	57.52	57.72	65.13	51.15	105.80	14.92
Nitrogen-free extract.....	64.02	66.26	66.02	64.98	88.90	80.90	95.91	85.54
Ether extract.....	58.35	55.35	62.09	58.09	85.13	80.15	90.87	85.53
Total nitrogen.....	52.53	49.73	50.34	51.41	62.71	56.32	68.98	59.22
Carbon.....	57.21	57.61	57.35	57.34	80.61	72.37	92.35	79.82
Energy.....	56.61	57.24	56.32	56.75	79.98	71.56	91.55	78.96

The average percentage digestibility of the hay, as computed from the aggregate feed and excreta of the three periods, did not differ as between the two animals to a greater extent than is often the case. The differences as regards dry matter, organic matter, and energy are about 2 per cent, for nitrogen about 1 per cent, for crude fiber about 3 per cent, and for the remaining ingredients less than 1 per cent.

The heavier hay and grain rations of period 3 as compared with the lighter ones of period 2 show a slight decrease of digestibility in the case of steer D (on hominy feed), and a decided decrease with steer G (on maize meal). In the latter case it is to be noted that the difference in the quantity consumed was also greater than with steer D and that the ratio of grain to hay was also greater.

METABOLIZABLE ENERGY

The data obtained regarding the amount of chemical energy escaping in feces, urine, and methane, and the metabolizable energy remaining have already been published (2), but the principal results are repeated in Table IX for convenience.

TABLE IX.—Losses of chemical energy—metabolizable energy

Feed, animal, and period.	Energy per kilogram of dry matter.					Metabolizable energy per kilogram of digestible organic matter.	Percentage losses.			Percentage metabolizable.
	Total.	Losses.			Metabolizable.		In feces.	In urine.	In methane.	
		In feces.	In urine.	In methane.						
	<i>Calories.</i>	<i>Calories.</i>	<i>Calories.</i>	<i>Calories.</i>	<i>Calories.</i>	<i>Calories.</i>				
Hay:										
Steer D, period 1.....	4,400	2,077	209	285	1,829	3,442	47.20	4.75	6.49	41.56
Steer D, period 4.....	4,391	1,837	234	332	1,990	3,406	41.83	5.33	7.54	45.30
Steer D, period 5.....	4,390	1,956	255	345	1,834	3,294	44.57	5.80	7.85	41.78
Steer G, period 1.....	4,393	1,906	208	300	1,979	3,463	43.39	4.75	6.82	45.04
Steer G, period 4.....	4,391	1,878	220	319	1,974	3,420	42.76	5.00	7.27	44.97
Steer G, period 5.....	4,390	1,917	238	358	1,877	3,313	43.68	5.41	8.15	42.76
Average.....	4,393	1,929	227	323	1,914	3,390	43.92	5.17	7.35	43.56
Hay and hominy feed:										
Steer D, period 2.....	4,560	1,261	209	403	2,687	3,775	27.65	4.58	8.84	58.93
Steer D, period 3.....	4,553	1,293	196	340	2,724	3,879	28.40	4.30	7.47	59.83
Average.....	4,557	1,277	203	371	2,706	3,827	28.02	4.44	8.15	59.39
Hay and maize meal:										
Steer G, period 2.....	4,483	897	189	443	2,954	3,701	20.00	4.22	9.88	65.90
Steer G, period 3.....	4,468	1,271	156	352	2,689	3,763	28.45	3.49	7.88	60.18
Average.....	4,476	1,084	173	398	2,821	3,732	24.22	3.87	8.89	63.02
Hominy feed (computed):										
Steer D, period 2.....	4,720	542	195	496	3,487	3,993	11.48	4.13	10.50	73.89
Steer D, period 3.....	4,698	603	167	371	3,557	4,156	12.83	3.56	7.90	75.71
Average.....	4,709	573	181	433	3,522	4,075	12.15	3.84	9.20	74.81
Maize meal (computed):										
Steer G, period 2.....	4,526	382	175	509	3,460	3,776	8.45	3.87	11.25	76.43
Steer G, period 3.....	4,508	948	125	372	3,063	3,869	21.04	2.78	8.25	67.93
Average.....	4,517	665	150	441	3,261	3,822	14.74	3.32	9.75	72.19

With steer D the heavier ration of period 3 as compared with period 2 resulted in a slightly greater loss in the feces, which, however, was slightly more than offset by lessened losses in urine and methane, so that the percentage metabolizable in the total ration was practically the same. With steer G, on the contrary, the much heavier ration of period 3 caused a marked falling off in digestibility which was only partially compensated by smaller losses in the urine and methane, so that the percentage metabolizable was distinctly less.

HEAT PRODUCTION

The heat production as measured by the respiration calorimeter compared with that computed in the ordinary manner from the balance of carbon and nitrogen is shown in Table X.

TABLE X.—Observed and computed daily heat production

Animal and period.		Observed.	Computed.	Difference.	Computed +observed.
Steer D:		Calories.	Calories.	Calories.	Per cent.
Period 1	First day.....	11,276	11,951	675	106.0
	Second day.....	11,817	12,327	510	104.0
Period 2	First day.....	9,411	9,635	224	102.4
	Second day.....	9,782	9,992	210	102.1
Period 3	First day.....	13,845	13,593	252	98.2
	Second day.....	14,030	14,038	8	100.1
Period 4	First day.....	9,301	9,257	44	99.5
	Second day.....	9,092	9,198	106	101.2
Period 5	First day.....	7,899	7,940	41	100.5
	Second day.....	8,006	8,082	76	100.9
Steer G:					
Period 1	First day.....	11,669	11,601	68	99.4
	Second day.....	11,752	11,683	69	99.4
Period 2	First day.....	8,176	8,185	9	100.1
	Second day.....	8,218	8,275	57	100.7
Period 3	First day.....	13,307	12,829	478	96.4
	Second day.....	13,274	12,786	488	96.3
Period 4	First day.....	9,068	9,080	12	100.1
	Second day.....	8,806	8,806	0	100.0
Period 5	First day.....	6,938	6,786	152	97.8
	Second day.....	6,827	7,004	177	102.6

STANDING AND LYING

Standing and lying have been found to exert such an influence on the heat production of cattle that, in order to make comparisons, the observed results must be corrected to a uniform proportion of time standing and lying. The total heat production of each day of the 2-day periods has therefore been corrected to 12 hours' standing and 12 hours' lying in the manner described on page 454 of the paper already referred to (2) and the two days averaged. The distribution of this corrected heat production has also been computed by the method explained on page 468 of the same publication. The results of these computations are recorded in Table XI.

TABLE XI.—Heat production corrected to 12 hours' standing

Animal and period.	Dry matter eaten.		Corrected heat production.			Analysis of heat production.			
	Hay.	Grain.	First day.	Second day.	48-hour mean.	Standing 12 hours.	Rising and lying down.	Methane fermentation.	Remainder.
Steer D:									
Period 1.....	Grams. 6,204	Grams. 11,775	Calories. 12,995	Calories. 12,359	Calories. 1,679	Calories. 79	Calories. 805	Calories. 9,796	
Period 2.....	1,747	1,764	9,782	10,126	9,947	71	643	7,538	
Period 3.....	3,910	3,949	14,877	15,040	14,936	1,850	1,216	11,768	
Period 4.....	3,498	.....	9,481	9,680	9,625	1,498	527	7,524	
Period 5.....	1,786	.....	8,291	8,259	8,258	1,497	57	282	6,422
Steer G:									
Period 1.....	6,092	.....	12,211	11,971	12,098	1,802	80	830	9,386
Period 2.....	790	1,542	8,678	8,362	8,470	1,505	74	470	6,421
Period 3.....	2,383	4,644	14,510	14,467	14,561	2,852	68	1,126	10,515
Period 4.....	3,149	.....	9,843	9,242	9,568	1,958	75	457	7,078
Period 5.....	1,608	.....	7,811	7,178	7,477	1,382	62	261	5,772

ENERGY EXPENDITURE CONSEQUENT ON FEED CONSUMPTION

It is a familiar fact that the consumption of feed tends to stimulate the metabolism of an animal, as is manifested by the increased amount of heat produced. The energy thus expended, as well as the chemical energy escaping in the excreta, must be deducted from the gross energy of a feeding stuff to obtain its net energy value. In this experiment the losses of energy in heat production per kilogram of dry matter, computed as in previous papers, are recorded in Table XII.

TABLE XII.—Increment of heat production per kilogram of dry matter

Feedstuff.	Animal, No.	Periods compared.	Total increment per kilogram.	Analysis of increment.			
				Standing 12 hours.	Rising and lying down.	Methane fermentation.	Remainder.
Mixed hay.....	D	1 and 5	Calories. 928	Calories. 41	Calories. 5	Calories. 118	Calories. 764
Do.....	G	1 and 5	1,031	94	4	137	806
Average.....			980	67	5	123	785
Mixed hay and hominy feed..	D	2 and 3	1,147	36	7	132	972
Mixed hay and maize meal..	G	2 and 3	1,297	287	-1	140	871
Computed for hominy feed.....	D	2 and 3	1,365	30	9	146	1,180
Computed for maize meal.....	G	2 and 3	1,434	386	-4	146	906

One kgm. of maize dry matter appears to have caused a somewhat greater increase (about 5 per cent) in heat production than the same amount of hominy feed. A marked difference is manifested in the proportion of the increase due to standing, while the heat evolved by fermentation is substantially equal, and the direct stimulus to the metabolism ("remainder") is less with maize. The total difference is probably not very significant.

NET ENERGY VALUES

By subtracting from the gross energy of the hominy feed and maize meal, respectively, the losses of chemical energy in the feces, urine, and methane, as shown in Table IX, and the energy expenditure consequent upon its consumption as measured by the increment of heat production shown in Table XII, the following net energy values for the two feeding stuffs may be computed. Later investigations on maize meal (3), however, led to the conclusion that the figure obtained in this experiment for the heat expenditure in feed consumption was too high, and that 1,289 Calories per kilogram of dry matter was more nearly correct. The results in Table XIII are computed, using both factors.

TABLE XIII.—*Net energy values per kilogram of dry matter*

Feedstuff.	Gross energy.	Losses in excreta.	Expended in feed consumption.	Net energy value.
	<i>Calories.</i>	<i>Calories.</i>	<i>Calories.</i>	<i>Calories.</i>
Hominy feed.....	4,709	1,187	1,365	2,157
Maize meal.....	4,517	1,256	1,434	1,827
Maize meal, corrected result	4,517	1,256	1,289	1,972

COMPARISON WITH OTHER RESULTS

The results of this experiment indicate a distinct, although not great, superiority per kilogram of the hominy feed over the maize meal from which it was made. Before generalizing this conclusion it is obviously desirable to make such comparisons as are possible with results of other experiments.

AVERAGE RESULTS ON MAIZE MEAL

Additional determinations on the influence of maize meal upon the heat production, designated as experiments 179 and 220, have been reported from this Institute, and the results of 12 determinations of its digestibility have been averaged by Henry and Morrison (5). As Table II shows, the maize meal used in the trials just described did not differ materially in composition from that used in our other experiments nor from the composition shown by Henry and Morrison's average. The percentage digestibility of the ingredients of the samples of maize meal used in our several experiments (including the results already reported in Table VIII) is shown in Table XIV.

TABLE XIV.—*Percentage digestibility of maize meal*

Constituent.	Experiment 179.		Experiment 211.		Experiment 220.		
	Period 3.	Period 4.	Period 2.	Period 3.	Period 3.	Period 4.	Period 5.
Dry matter.....	64.91	76.23	91.63	79.55	89.78	81.54	90.63
Organic matter.....	66.26	77.68	93.16	80.45	90.15	82.37	91.55
Total nitrogen.....	63.68	61.58	68.98	59.22	69.68	59.21	71.77
True protein.....	57.05	58.01	71.06	59.95	74.74	65.46	76.34
Crude fiber.....	44.79	49.05	.....	14.92	76.27	17.42	8.68
Nitrogen-free extract.....	77.75	88.20	95.91	85.54	93.19	86.61	95.95
Ether extract.....	74.71	83.89	90.87	85.53	85.52	83.96	90.68
Energy.....	63.16	74.93	91.55	78.96	88.29	80.40	89.12

The results obtained in experiment 179, period 3, appear to have been abnormally low. The average of the 6 others, compared with Henry and Morrison's average of 12 experiments, is as follows (Table XV):

TABLE XV.—*Average percentage digestibility of maize meal*

Constituent.	Our experiments.	Henry and Morrison's average.
Dry matter.....	84.89	90
Organic matter.....	85.89	.....
Total nitrogen.....	65.07	74
True protein.....	67.57	.....
Crude fiber.....	27.72	57
Nitrogen-free extract.....	90.90	94
Ether extract.....	86.74	93
Energy.....	83.88	.....

Our averages are slightly lower than Henry and Morrison's. The latter did not include in their compilation experiments in which the nutritive ratio of the total ration was 1 to 12 or wider.¹ In all but one of our six experiments the nutritive ratio approached or passed 1 to 12, and this may account for the slightly lower digestibility. On the other hand, the lower digestibility in such cases appears to be due to a considerable extent to lessened fermentation of the carbohydrates and a correspondingly decreased loss of energy in methane, so that, as the writers have pointed out, a certain degree of compensation occurs as to the energy values and particularly as to the metabolizable energy per unit of digestible organic matter (2, p. 446, 451). It appears probable, therefore, that the factors for the latter quantity obtained in our experiments may be applied safely to other experiments also.

The metabolizable energy of maize meal in our experiments, computed as in Table IX (omitting experiment 179, period 3), was as shown in Table XVI. Henry and Morrison's results afford no data for a comparison of this sort.

TABLE XVI.—*Metabolizable energy of maize meal*

Experiment No.	Per kilogram dry matter.	Per kilogram digestible organic matter.
	<i>Calories.</i>	<i>Calories.</i>
Experiment 179, Period 4.....	3,392	3,716
Experiment 211, Period 2.....	3,460	3,776
Experiment 211, Period 3.....	3,063	3,869
Experiment 220, Period 3.....	3,334	3,753
Experiment 220, Period 4.....	3,129	3,851
Experiment 220, Period 5.....	3,200	3,543
Average.....	3,263	3,751

¹ Private communication.

It would appear that the factor 3.9 therms per kilogram of digestible organic matter proposed by the writers (2, p. 453) for concentrates containing less than 5 per cent of fat is somewhat high for maize meal and that 3.8 would be more nearly correct. Applying the latter factor to Henry and Morrison's averages for the digestible nutrients, and using the average result for the heat increment per kilogram of dry matter which was reported in a previous paper—viz, 1.289 therms per kilogram dry matter—gives the results in Table XVII.

TABLE XVII.—Energy values of average maize meal per kilogram dry matter

	Calories.
Metabolizable energy.....	3,402
Energy expended in feed consumption.....	1,289
Net energy value.....	2,113

AVERAGE RESULTS ON HOMINY FEED

The composition of our sample, as shown by Table I, corresponded substantially to Henry and Morrison's average of 778 samples of high-grade hominy feed. No other determinations on the influence of hominy feed upon the heat production of an animal have been reported, but the average of nine determinations by Lindsey (6, 7) of its digestibility by sheep is given by Henry and Morrison (5, p. 647).

A reference to the original shows that the "English hay" used in eight out of the nine experiments was notably lower in protein than the mixed hay used in our experiments. Whether or not as a consequence of this lack of protein, three experiments out of the nine showed coefficients distinctly lower than the remainder—viz, for dry matter 71 per cent, 75 per cent, and 78 per cent. If these three apparently exceptional results are omitted, the average of the remaining six corresponds very well with our data, as Table XVIII shows.

TABLE XVIII.—Percentage digestibility of hominy feed

Constituent.	Lindsey's results.		Our results (two ex- periments).	Average of Lindsey's six and our two experi- ments.
	Nine ex- periments.	Six experi- ments.		
Dry matter.....	82.94	87.16	87.27	87.19
Organic matter.....			88.91	88.91
Total nitrogen.....	65.53	68.59	72.12	69.47
True protein.....			67.34	67.34
Crude fiber.....	75.60	87.87	78.94	85.64
Nitrogen-free extract.....	89.61	92.18	91.54	92.82
Ether extract.....	91.16	90.00	95.92	91.48

Regarding the figures of the last column of Table XVIII as representing the average digestibility of hominy feed, we may compute from the

average composition as shown in Henry and Morrison's compilation (Table I) the digestible organic matter. Multiplying the latter by the factor 4.075 Calories per gram obtained in our experiments, we may compute the energy values of average hominy feed to be as follows (Table XIX):

TABLE XIX.—Energy values of average hominy feed per kilogram of dry matter

	Calories.
Metabolizable energy.....	3,542
Energy expended in feed consumption.....	1,365
Net energy value.....	2,177

The results of the foregoing comparisons agree with those of Experiment 211 in giving a somewhat higher net energy value for hominy feed than for maize meal, although the difference is small in both cases, and in the average results hardly significant (Table XX).

TABLE XX.—Average net energy values per kilogram of dry matter

Feedstuff.	From ex- periment 211.	Computed from aver- age results.
	Calories.	Calories.
Maize meal.....	1,972	2,113
Hominy feed.....	2,157	2,177

From the foregoing results and from the data contained in Table V it may be computed that the partition of the net energy of maize between the hominy and the total by-products included in the hominy feed is as follows:

TABLE XXI.—Percentage partition of net energy of maize

Feedstuff.	Computed from ex- periment 211.	Computed from aver- age results.
In hominy feed.....	33.67	31.72
In hominy.....	66.33	68.28
In maize.....	100.00	100.00

CORRECTION OF EARLIER TABLES

In three earlier publications (1, 4, 8) there has appeared a table of net energy values of feeding stuffs for cattle computed in the manner proposed by the writers (2, p. 486) from Henry and Morrison's figures for digestible nutrients (5, p. 653). The foregoing results indicate that the averages given in that table for maize and hominy feed require some correction.

In the case of maize the metabolizable energy was estimated at 3.9 Calories per gram of digestible organic matter as in the case of other similar concentrates. As shown above, the actual average is about 3.75 Calories per gram—that is, lower than that of other concentrates which have been experimented with—so that the tabulated results are somewhat too high.

In the case of the hominy feed an error was made, we believe, in the other direction by using too low figures for the average digestibility of this material. On the basis of the results here discussed, we submit the following corrections (Table XXII) for the table referred to:

TABLE XXII.—Net energy values per 100 pounds (with average water content) for cattle

Feedstuff.	As published.	Corrected.
	Therms.	Therms.
Maize, dent.....	89.16	85.50
Maize, flint.....	87.50	84.00
Maize meal.....	88.75	85.20
Hominy feed.....	81.31	88.78

SUMMARY

A comparison is reported of the metabolizable energy and of the net energy value of hominy feed as determined in an experiment on a grade Hereford steer with the corresponding values for maize meal ground from the same grain, as determined in a parallel experiment on a full-blood Hereford of about the same age. Data are also reported as to the partition of the ingredients and energy of maize meal among the products of its milling for the production of hominy.

An increase in the amount of the mixed ration of hay and hominy feed consumed resulted in a slightly decreased digestibility, while a greater increase in the amount of mixed hay and maize meal consumed caused a considerable decrease in digestibility.

The average percentage losses of energy in the excreta were greater with maize meal than with hominy feed, chiefly on account of the somewhat lower digestibility of the former, notably in the heavier ration.

The metabolizable energy per kilogram of dry matter and per kilogram of digestible organic matter was greater for the hominy feed than for the maize meal, the difference being due to the higher gross energy and smaller losses in the former case.

The increment of heat production by the animal per kilogram of dry matter consumed was slightly less for the hominy feed than for the maize meal but slightly greater than the average of all experiments on the latter material.

The net energy value of the hominy feed in this experiment was distinctly greater than that of the maize meal. A computation of the net

energy values based on the average composition and digestibility of the two materials reduced this difference to an insignificant amount.

Corrections are reported for the net energy values of hominy feed and maize meal contained in earlier tables.

LITERATURE CITED

- (1) ARMSBY, H. P.
1916. THE USE OF ENERGY VALUES IN THE COMPUTATION OF RATIONS FOR FARM ANIMALS. U. S. Dept. Agr. Bul. 459, 29 p.
A revision of Farmers' Bul. 346.
- (2) ——— and FRIES, J. A.
1915. NET ENERGY VALUES OF FEEDING STUFFS FOR CATTLE. *In Jour. Agr. Research*, v. 3, no. 6, p. 435-491, 2 fig. Literature cited, p. 489-491.
- (3) ——— and BRAMAN, W. W.
1916. ENERGY VALUES OF RED-CLOVER HAY AND MAIZE MEAL. *In Jour. Agr. Research*, v. 7, no. 9, p. 379-387.
- (4) ——— and PUTNEY, F. S.
1916. NET ENERGY VALUES OF AMERICAN FEEDING STUFFS. *In Penn. Agr. Exp. Sta. Bul. 142*, p. 15-20.
- (5) HENRY, W. A., and MORRISON, F. B.
1915. FEEDS AND FEEDING . . . ed. 15, 691 p. Madison, Wis.
- (6) LINDSEY, J. B.
1904-05. DIGESTION EXPERIMENTS WITH SHEEP. *In Mass. Agr. Exp. Sta. 16th Ann. Rpt. [1902/03]*, p. 63-79, 1904; 17th Ann. Rpt. [1903/04], p. 45-77, 1905.
- (7) ——— HOLLAND, E. B., and SMITH, P. H.
1907. THE DIGESTIBILITY OF CATTLE FOODS. *In Mass. Agr. Exp. Sta. 19th Ann. Rpt. [1905/06]*, p. 96-156.
- (8) PUTNEY, F. S., and ARMSBY, H. P.
1916. COMPUTATION OF DAIRY RATIONS. *Penn. Agr. Exp. Sta. Bul. 143*, 24 p.

THE INFLUENCE OF THE DEGREE OF FATNESS OF CATTLE UPON THEIR UTILIZATION OF FEED*

By HENRY PRENTISS ARMSBY, Director, and J. AUGUST FRIES, Assistant
Director, Institute of Animal Nutrition of The Pennsylvania
State College.

In the fattening of cattle it is a common experience that the gain in live weight secured per unit of feed consumed diminishes as the fattening progresses. Little reflection is required to make it evident that this phenomenon may be the combined result of a variety of causes. A supposed lower utilization of feed by the fattened as compared with the thin animal has been regarded not uncommonly as one such cause. It has been supposed that with the progress of the fattening the body cells become less efficient in the manufacture of fat from other nutrients or that the cells of the adipose tissue, as they become loaded with fat, offer, as it were, an increasing resistance to the deposition of added fat, to overcome which requires an expenditure of energy. In either case a unit of a resorbed nutrient, such as dextrose for example, would yield less fat than in the thin animal while the heat production would be correspondingly increased and the net energy value of the feed reduced.

The investigation here reported was undertaken to test the relative importance of this as compared with other possible factors by means of a direct comparison of the utilization of feed energy by the same steer in ordinary condition and when well fattened. Although it includes only a single comparison on one animal the results appear of some interest in view of the paucity of experimental evidence on this point.

OUTLINE OF EXPERIMENT

The subject of the experiment was a pure-bred Shorthorn steer about two years and nine months old at the beginning of the experiment. He was a very quiet and docile animal. During the winter of 1912-13 he was the subject of a series of respiration calorimeter trials (unreported). During the following summer he

*Co-operative investigations between the Institute of Animal Nutrition of The Pennsylvania State College and the Bureau of Animal Industry of the United States Department of Agriculture.

was on pasture and gained some 240 pounds in weight. On October 21, 1913, he weighed 1141 pounds and was put on a preliminary ration of the same feed mixture used in the experiment proper, which began on November 2, 1913. At that time the animal was in good condition, but not fat. A standard feed, consisting of one part by weight (air dry) of alfalfa hay and two parts of a mixture of concentrates, was used throughout the experiment. The mixture of concentrates employed consisted of one part by weight (air dry) of cottonseed meal, two parts of wheat bran and six parts of maize meal. During Period I an approximate maintenance ration of this standard feed was given while during Period II this amount was increased to the maximum which the animal would consume. A comparison of these two periods in the same manner as in previous investigations served to show the utilization of the feed by the animal.

At the close of Period II, on December 22, the steer was placed in the hands of the Animal Husbandry Department of the College for fattening and was fed by them until March 14, 1914, during which time he gained about 300 pounds and was brought into prime condition.

In the second half of the experiment, beginning March 15, 1914, the comparison of Periods I and II was repeated in the reverse order. In Period III the animal was given as heavy a ration of the standard feed mixture as he would consume, a little being, in fact, left uneaten. This was followed by Period IV, in which an approximate maintenance ration was fed. A comparison of Periods III and IV served to show the utilization of feed energy by the fattened animal.

METABOLIZABLE ENERGY

The losses of energy in feces, urine and methane in each period were determined in the usual manner. The results afford data for computing for the total rations the percentage losses of energy in the several excreta and the percentage metabolizable. On the assumption that the corresponding values for the alfalfa hay were the same as those found for the same hay in the experiment upon the same animal during the previous year, the corresponding figures for the concentrate mixture may also be computed. The results are recorded in Table I.

TABLE I
PERCENTAGE DISTRIBUTION OF ENERGY

	Percentage Losses			Percentage Metabolizable
	In feces	In urine	In methane	
<i>Total ration:</i>				
Period I.....	24.44	5.16	9.15	61.25
Period II.....	26.61	4.55	6.72	62.12
Period III.....	25.88	4.91	6.48	62.73
Period IV.....	24.42	5.38	8.80	61.40
<i>Assumed for hay.....</i>	42.60	5.92	6.77	44.71
<i>Computed for concentrates</i>				
Period I.....	15.62	4.79	10.30	69.29
Period II.....	18.81	3.88	6.70	70.61
Period III.....	17.80	4.42	6.34	71.44
Period IV.....	15.64	5.11	9.78	69.47

As in earlier experiments, the heavier rations suffered relatively greater losses of energy in the feces but smaller ones in urine and methane, so that the percentage of the gross energy which was metabolizable was slightly greater on the heavier ration. It must be remembered also that the metabolizable energy as here computed includes that evolved as heat in the methane fermentation. Estimating this at 6.07 Cals. per gram of methane*, the proportion of the gross energy of the rations which was available to sustain the tissue metabolism averaged 57.24 per cent. for the lighter rations and 59.43 per cent. for the heavier. No distinct difference in this respect was manifest between the unfattened and fattened condition.

BODY INCREASE

From the income and outgo of nitrogen and carbon as determined with the respiration calorimeter the amounts of protein and fat stored in the body may be computed upon the usual assumption that the stock of carbohydrates in the body remained substantially unchanged. The average results for the four periods are contained in Table II.

* Jour. Agr. Research, 1915, v. 3, No. 6, p. 468.

TABLE II
DAILY GAINS OF PROTEIN AND FAT

	Protein	Fat	Total Organic Matter
	Grams	Grams	Grams
Period I.....	14.4	89.0	103.4
Period II.....	120.0	822.0	942.0
Period III.....	107.4	615.9	723.3
Period IV.....	-51.0	-28.3	-79.3

The foregoing figures may serve as the basis for some approximate comparisons. Assuming the percentage of organic matter in the total gain in live weight to have been the same as that observed by Lawes and Gilbert for fattening cattle, viz., 73.89, the gains of organic matter recorded in Table II, are equivalent to a gain in weight of 1.275 Kgs. (2.8 lbs.) per day in Period II and 0.979 Kgs. (2.2 lbs.) in Period III. The experimental periods were too short to permit very satisfactory conclusions to be drawn from the live weights of the animals but the rates of gain just computed appear to correspond fairly well with the observed weights.

A comparison of these estimated gains in weight with the feed consumption yields the results of Table III. Obviously, no great accuracy can be claimed for these computations, but nevertheless they show clearly a decreasing efficiency of the total feed.

TABLE III
FEED CONSUMED PER UNIT OF ESTIMATED GAIN IN WEIGHT

	Total Feed	Dry Matter	Digestible Organic Matter
Period II.....	8.2	7.2	5.2
Period III.....	11.6	10.1	9.6

ENERGY EXPENDITURE CONSEQUENT UPON FEED CONSUMPTION

The average daily heat production of the animal, corrected to a uniform period of 12 hours standing and 12 hours lying, as in our earlier experiments was:

Period I.....	10905 Cals.
Period II.....	16511 Cals.
Period III.....	19992 Cals.
Period IV.....	14095 Cals.

The foregoing results show the same marked increase in heat production which has been uniformly found to follow an increase in the ration. From a quantitative comparison of the corresponding periods, the energy expenditure per unit of total feed (hay and concentrates) consumed may be computed in the case of the unfattened and fattened animal, respectively. The results of this computation are contained in Table IV. For the reasons stated in a previous paper* no attempt has been made to correct these results for the differences in live weight.

TABLE IV
ENERGY EXPENDITURE PER KILOGRAM DRY MATTER OF TOTAL RATION

	Dry Matter Eaten	Heat Production
	Grams	Cals.
Unfattened..	Period II.....	9146.3
	Period I.....	4462.9
	Difference.....	4683.4
	Difference per kilogram dry matter.....	1197
	Period III.....	9911.6
Fattened....	Period IV.....	5215.6
	Difference.....	4696.0
	Difference per kilogram dry matter.....	1256

*Jour. Agr. Research, 1915, v. 3, No. 6, p. 471.

The results are of quite the same order of magnitude as those obtained in previous experiments on similar mixed rations of hay and grain. In the fattened animal there appears to have been an increase of about 5 per cent. in the energy expended in the various processes intermediate between the prehension of the feed and the storage of protein and fat in the tissues. To this extent the experiment sustains the view outlined in the introductory paragraphs. The difference, however, is small and it is perhaps questionable whether it exceeds the experimental error. At any rate, it is far from accounting for the very marked difference in the economic utilization of the feed which is indicated by the approximate calculation of Table III and is of little significance in comparison with another factor to be considered immediately.

THE MAINTENANCE REQUIREMENT

The comparisons of Table IV also afford data for computing the basal katabolism of the steer in the manner described in an earlier publication.*

Each kilogram of dry matter consumed increased the katabolism by 1197 Cals. in the unfattened and by 1256 Cals. in the fattened state. It may be computed, therefore, by how much the katabolism would have been reduced had the feed been entirely withdrawn, while subtracting this amount from the observed heat production will give the fasting katabolism. The calculations for Periods I and IV are:

Period I, unfattened, $10,905 - (1197 \times 4.4629) = 5563$ Cals.
Period IV, fattened, $14,095 - (1256 \times 5.2156) = 7544$ Cals.

Similar computations for Periods II and III would, of course, yield the same results.

The results per head and also those computed to a uniform live weight of 1000 pounds for the sake of comparison with other data are shown in Table V.

*U. S. Dept. Agr., Bur. Anim. Indus., Bul. 128, p. 53.

TABLE V
COMPUTED FASTING KATABOLISM PER DAY

	Per Head	Per 1000 Pounds Live Weight	
		In Proportion to Weight	In Proportion to Two-thirds power of Weight
	Cals.	Cals.	Cals.
Unfattened.....	5563	4919	5125
Fattened.....	7544	5275	5943

In the unfattened state the animal had a rather low basal katabolism, the average of 23 similar determinations by the writers being 5906 Cals. per 1000 pounds as compared with 5125 Cals. in this case.

It is evident that the major factor determining the lower economic efficiency in the fattened state was the very marked increase (36%) in the basal katabolism. Doubtless this increase was due in part to the greater body weight to be supported while standing but, as the table shows, it was greater than would be computed from the increased weight or the surface as estimated by the Meeh formula. Apparently the accumulation of fat tended in some way to stimulate the general metabolism. These results are quite in harmony with those obtained by Kellner and Köhler in experiments on the same subject. This greater maintenance requirement, together with the relatively somewhat smaller feed consumption, was chiefly responsible for the more expensive gains by the fattened animal.

Another factor acting in the same direction is the probable greater energy content of a unit of gain in live weight. From the estimated increase in live weight and the daily gain of energy shown in Table 7, it may be computed that the energy content of one kilogram gain in weight was approximately:

In Period II.....6.970 Therms
In Period III.....8.042 Therms

In other words, the amount of either net or metabolizable energy in excess of maintenance required to produce a unit of gain in weight was greater with the fattened animal. This would be still more true if the maintenance were computed in proportion to weight or surface.

NET ENERGY VALUES

From the foregoing the net energy values of the rations may also be computed as shown in Table VI.

TABLE VI
NET ENERGY VALUES OF TOTAL RATIONS PER KILOGRAM DRY MATTER

	Gross energy	Losses in excreta	Heat increment	Net energy value
	Cals.	Cals.	Cals.	Cals.
Period I.....	4488	1739	1197	1552
Period II.....	4470	1693		1580
Period III.....	4481	1670	1256	1555
Period IV.....	4478	1728		1494
Average for light rations.....	4483	1733	1227	1523
Average for heavy rations.....	4476	1682	1227	1567
Average in unfattened condition.....	4479	1716	1197	1566
Average in fattened condition.....	4480	1699	1256	1525

The relations shown in Tables IV and VI may also be expressed in another way by comparing the percentages of the metabolizable energy which were recovered in the gain made in the unfattened and fattened states, respectively, as shown by the energy balances.

TABLE VII
PERCENTAGES OF METABOLIZABLE ENERGY RECOVERED IN GAIN

	Metabolizable Energy	Body Gain	Percentage Recovered	
	Cals.	Cals.	Per Cent.	
Unfattened..	Period II.....	25398	8887	....
	Period I.....	12269	1364	....
	13129	7523	57.3	
Fattened....	Period III.....	27865	7873	....
	Period IV.....	14338	243	....
	13527	7630	56.4	

SUMMARY

1. A steer in medium conditions received, in two successive periods, an approximate maintenance ration and a fattening ration of the same standard mixture of hay and concentrates. The animal was then fattened and the comparison of a maintenance ration and a fattening ration of the same standard feed mixture was repeated.

2. In consequence of the smaller losses in the urine and especially in the combustible gases the percentage of the gross energy of the feed which was metabolizable was greater on the heavier than on the lighter rations. No difference in this respect was observed between the fattened and the unfattened animal.

3. The heat increment resulting from the consumption of a unit of feed was but little greater in the fat than in the thin animal. Consequently the net energy values of the feed and the percentages of the metabolizable energy which were available for gain were but slightly less in the fattened than in the unfattened condition.

4. The maintenance requirement of the steer was increased 36 per cent. by a three-months fattening in which the live weight was increased by about 300 pounds. This increase was greater than corresponded to the increase in weight or in computed body surface.

5. The lower economic efficiency of the fattened animal in this experiment was due chiefly to his higher maintenance requirement and only to a small extent if at all to a difference in the utilization of the surplus of feed over the maintenance requirement.

INFLUENCE OF THE DEGREE OF FATNESS OF CATTLE UPON THEIR UTILIZATION OF FEED

By HENRY PRENTISS ARMSBY, *Director*, and J. AUGUST FRIES, *Assistant Director*,
Institute of Animal Nutrition of The Pennsylvania State College

COOPERATIVE INVESTIGATIONS BETWEEN THE BUREAU OF ANIMAL INDUSTRY
OF THE UNITED STATES DEPARTMENT OF AGRICULTURE AND THE INSTITUTE
OF ANIMAL NUTRITION OF THE PENNSYLVANIA STATE COLLEGE

INTRODUCTION

In the fattening of cattle it is a common experience that the gain in live weight secured per unit of feed consumed diminishes as the fattening progresses. Little reflection is required to make it evident that this phenomenon may be the combined result of a variety of causes. A supposed lower utilization of feed by the fattened as compared with the thin animal has been regarded not uncommonly as one such cause. It has been supposed that with the progress of the fattening the body cells become less efficient in the manufacture of fat from other nutrients or that the cells of the adipose tissue, as they become loaded with fat, offer, as it were, an increasing resistance to the deposition of added fat, to overcome which requires an expenditure of energy. In either case a unit of a resorbed nutrient, such as dextrose for example, would yield less fat than in the thin animal, while the heat production of the body would be correspondingly increased and the net energy value of the feed reduced.

The investigation here reported was undertaken to test this view by means of a direct comparison of the utilization of feed energy by the same steer in ordinary condition and when well fattened. Although it includes only a single comparison on one animal, the results appear of some interest in view of the paucity of experimental evidence on this point.

OUTLINE OF EXPERIMENT

The subject of the experiment was a pure-bred Shorthorn steer about 2 years and 9 months old at the beginning of the experiment. He was a very quiet and docile animal. During the winter of 1912-13 he was the subject of a series of respiration calorimeter trials (unreported). During the following summer he was on pasture and gained some 240

pounds in weight. On October 21 he weighed 1,141 pounds and was put on a preliminary ration of the same feed mixture used in the experiment proper. The latter began on November 2, 1913.¹ At that time the animal was in good condition but not fat. A standard feed, consisting of uniform proportions of alfalfa hay and a mixture of concentrates, was used throughout the experiment. During period 1 an approximate maintenance ration of this standard feed was given, while during period 2 the amount was increased to the maximum which the animal would consume. A comparison of these two periods in the same manner as in previous investigations served to show the utilization of the feed by the animal.

At the close of period 2, on December 22, the steer was placed in the hands of the Animal Husbandry Department of the College for fattening and was fed by them until March 14, during which time he gained about 300 pounds and was brought into prime condition. The appearance of the steer before and after fattening is shown by the two figures of plate 41, taken November 3 and March 14, respectively.

In the second half of the experiment, beginning March 15, 1914, the comparison of periods 1 and 2 was repeated in the reverse order. In period 3 the animal was given as heavy a ration of the standard feed mixture as it was thought he would consume, although in fact a little was left uneaten. This was followed by period 4, in which an approximate maintenance ration was fed. A comparison of periods 3 and 4 served to show the utilization of feed energy by the fattened animal.

RATIONS AND PERIODS

The mixture of concentrates employed consisted of 1 part by weight (air-dry) of cottonseed meal, 2 parts of wheat bran, and 6 parts of maize meal. The standard feed consisted of 2 parts by weight (air-dry) of this mixture and 1 part of alfalfa hay. The composition of the dry matter of the samples of these materials taken is shown in Table 1 of the Appendix. The slight fluctuations observed in the moisture content of the feeding stuffs from period to period was insufficient to cause more than an entirely insignificant variation in the proportions of dry matter supplied by the several feeding stuffs. As Table 2 of the Appendix shows, the protein was ample for a fattening animal of this age according to the accepted standards.

The dates of the several periods and the rations consumed are shown in Table I.

¹ The dates given refer in every instance to the 24 hours ending at 6 p. m. on the day named.

TABLE I.—Periods and rations

Period.	Preliminary period.	Digestion period.	Daily rations.	
			Hay.	Concentrates.
			Kgm.	Kgm.
Period 1	November 2-12	November 13-22	1.7	3.4
Transition	November 23-29 ....	.....	.....	.....
Period 2	November 30-December 10.	December 11-20	3.5	7.0
Period 3	March 15-25	March 26-April 4 ...	3.8	7.6
Period 4	April 5-15	April 16-25	2.0	4.0

DIGESTIBILITY

The digestibility of the several rations was determined in the usual manner, the results in detail being contained in Table 2 of the Appendix. The feces in period 3 were very watery, but it does not appear that this resulted in any lower digestibility. The percentage digestibility of the several nutrients in the four periods is shown in Table II.

TABLE II.—Digestibility of rations

Constituent.	Before fattening.		After fattening.	
	Period 1 (light ration).	Period 2 (heavy ration).	Period 3 (heavy ration).	Period 4 (light ration).
	Per cent.	Per cent.	Per cent.	Per cent.
Dry matter	76.4	74.2	74.8	76.7
Ash	45.9	42.6	46.5	51.7
Organic matter	78.1	75.6	76.4	78.1
Protein	75.6	71.6	75.9	75.7
Non-protein	62.4	59.8	23.2	67.7
Crude fiber	43.2	45.1	41.4	42.9
Nitrogen-free extract	85.7	83.6	84.0	85.8
Ether extract	82.2	79.6	84.3	81.8
Total nitrogen	75.2	71.4	69.8	75.8
Carbon	76.2	74.0	74.6	76.1
Energy	75.6	73.4	74.1	75.6

EFFECT OF AMOUNT OF FEED.—Both before and after fattening the heavier rations showed a distinctly lower digestibility than the lighter ones, the exception being the crude fiber in periods 1 and 2 and the protein and ether extract in periods 3 and 4. The averages for dry matter, nitrogen, carbon, and energy are contained in Table III.

TABLE III.—Average digestibility of light and heavy rations

Constituent.	Light ration.	Heavy ration.
Dry matter.....per cent..	76.5	74.5
Nitrogen.....do.....	75.5	70.6
Carbon.....do.....	76.1	74.3
Energy.....do.....	75.6	73.8
Dry matter eaten per 1,000 pounds of live weight.....pounds....	8.62	16.20

Qualitatively the results correspond to those of other experiments both here and elsewhere (1, p. 613-618)¹, but quantitatively the difference is less than has usually been observed, a fact for which no obvious reason appears.

EFFECT OF FATTENING.—Fattening appears to have had no distinct influence on the digestibility, the exceptions being the protein, non-protein, crude fiber, and ether extract in period 3. The average percentages for the same ingredients as in Table III are shown in Table IV.

TABLE IV.—Average digestibility before and after fattening

Constituent.	Before.	After.
	<i>Per cent.</i>	<i>Per cent.</i>
Dry matter.....	75.3	75.8
Nitrogen.....	73.3	72.8
Carbon.....	75.1	75.4
Energy.....	74.5	74.8

URINARY EXCRETION

The results upon the urine are recorded in Table 3 of the Appendix and are summarized in Table V.

TABLE V.—Average daily excretion in urine

Period No.	Nitrogen.	Carbon.	Energy.	Ratio of nitrogen to carbon.	Energy per gram of nitrogen.	Energy per gram of carbon.
	<i>Gm.</i>	<i>Gm.</i>	<i>Calories.</i>		<i>Calories.</i>	<i>Calories.</i>
1.....	79.5	107.5	1,015.9	1:1.35	12.78	9.45
2.....	139.4	191.6	1,712.1	1:1.37	12.28	8.94
3.....	155.6	218.9	2,045.8	1:1.41	13.15	9.34
4.....	107.0	136.1	1,318.8	1:1.27	12.32	9.65

The percentages of the nitrogen, carbon, and energy of the feed which were excreted in the urine are shown in Table VI, from which it appears that the relative losses through this channel were less on the heavier

¹ Reference is made by number (italic) to "Literature cited," p. 464.

rations of periods 2 and 3 than on the lighter rations, and that they were on the average a little greater in the fattened than in the unfattened animal.

TABLE VI.—Percentage losses in urine

Period No.	Percentage of total—			Percentage of digestible—		
	Nitrogen.	Carbon.	Energy. ^a	Nitrogen.	Carbon.	Energy. ^a
1.....	71.04	5.25	5.16	94.53	6.89	6.83
2.....	61.54	4.58	4.55	86.26	6.19	6.20
3.....	61.84	4.81	4.91	88.56	6.45	6.62
4.....	80.51	5.69	5.38	107.75	7.47	7.11

^a Corrected to N equilibrium.

COMBUSTIBLE GASES

Fries (5) has shown that the large number of respiration experiments executed here during the last 15 years seem to demonstrate beyond question that the fermentation gases given off by cattle on normal rations have substantially the composition of methane. The results of the present trials (Appendix, Table 5) are entirely in accord with those of earlier ones and show a ratio of hydrogen to carbon corresponding substantially with that of methane (1:2.976). The slight deficiency of hydrogen in most cases we ascribe to the difficulty of securing complete oxidation of the last traces of this element. Table VII shows the ratio of hydrogen to carbon and the computed amounts of methane, both per head and per 100 parts of digestible carbohydrates. In accord with our earlier results (3, 4) the extent of the fermentation of the carbohydrates, as measured by the methane excretion, was decidedly less on the heavier than on the lighter rations. The range of the results is substantially the same as in previous experiments on similar rations, particularly those in which alfalfa hay was used.

TABLE VII.—Production of combustible gases

Period No.	Ratio of hydrogen to carbon.	Methane computed from carbon.	
		Total per day and head.	Per 100 Gms. of digested carbohydrates. ^a
		<i>Gm.</i>	<i>Gm.</i>
1.....	1:2.970	137.3	5.2
2.....	1:3.063	206.0	3.8
3.....	1:3.010	215.8	3.7
4.....	1:3.048	154.0	5.0

^a Crude fiber plus nitrogen-free extract.

METABOLIZABLE ENERGY

Tables 2 to 5 of the Appendix afford data for computing the percentage losses of energy in the several excreta and the percentage metabolizable. On the assumption that the corresponding values for the alfalfa hay were the same as those found for the same hay in an experiment upon the same animal during the previous year, the corresponding figures for the concentrate mixture may also be computed. The results are recorded in Table VIII.

TABLE VIII.—Percentage distribution of energy

Item.	Percentage losses.			Percentage metabolizable.
	In feces.	In urine.	In methane.	
Total ration:				
Period 1.....	24.44	5.16	9.15	61.25
Period 2.....	26.61	4.55	6.72	62.12
Period 3.....	25.88	4.91	6.48	62.73
Period 4.....	24.42	5.38	8.80	61.40
Assumed for hay.....	42.60	5.92	6.77	44.71
Computed for concentrates:				
Period 1.....	15.62	4.79	10.30	69.29
Period 2.....	18.81	3.88	6.70	70.61
Period 3.....	17.80	4.42	6.34	71.44
Period 4.....	15.64	5.11	9.78	69.47

As in earlier experiments, the heavier rations suffered relatively greater losses of energy in the feces but smaller ones in the urine and methane, so that the percentage of the gross energy which was metabolizable was slightly greater in the heavier rations. It must be remembered also that the metabolizable energy as here computed includes that evolved as heat in the methane fermentation. Estimating this at 6.07 Calories per gram of methane (2, p. 468) the proportion of the gross energy of the rations which was available to sustain the tissue metabolism averaged 57.24 per cent for the lighter rations and 59.43 per cent for the heavier. No distinct difference in this respect is manifest between the unfattened and fattened condition.

The results recorded in Table IX show a close agreement with those of earlier experiments on similar rations.

TABLE IX.—Average losses of chemical energy and metabolizable energy

Item.	Gross energy per kilogram of dry matter.	Losses of chemical energy per kilogram of dry matter.	Metabolizable energy.	
			Per kilogram of dry matter.	Per kilogram of digestible organic matter.
	Calories.	Calories.	Calories.	Calories.
Total ration:				
Period 1.....	4,488	1,739	2,749	3,720
Period 2.....	4,470	1,693	2,995	3,856
Period 3.....	4,481	1,670	2,811	3,886
Period 4.....	4,478	1,728	2,749	3,719
Average.....	4,478	1,699	2,779	3,820
Assumed for hay.....	4,334	2,396	1,938	3,507
Computed for concentrates:				
Period 1.....	4,562	1,401	3,161	3,785
Period 2.....	4,537	1,334	3,203	3,980
Period 3.....	4,554	1,300	3,253	4,014
Period 4.....	4,548	1,389	3,159	3,788
Average.....	4,549	1,343	3,206	3,925

BODY INCREASE

From the income and outgo of nitrogen and carbon recorded in the tables of the Appendix the amounts of protein and fat stored in the body may be computed upon the usual assumption that the stock of carbohydrates in the body remained substantially unchanged. The average results for the four periods are contained in Table X.

TABLE X.—Daily gains of protein and fat

Period No.	Protein.	Fat.	Total organic matter.
	Grams.	Grams.	Grams.
1.....	14.4	89.0	103.4
2.....	120.0	822.0	942.0
3.....	107.4	615.9	723.3
4.....	— 51.0	— 28.3	— 79.3

The rations of periods 1 and 4, as intended, were approximately maintenance rations. Those of periods 2 and 3 were sufficient to support a tolerably rapid fattening. As appears from Table 8 of the Appendix, the measured gain of energy differed from that computed from the gains of protein and fat, being greater in every instance. The conclusions of subsequent paragraphs are based on the energy balances corrected to 12 hours' each standing and lying, but the results for protein and fat may serve as the basis for some approximate comparisons. If

the percentage of organic matter in the total gain in live weight is assumed to have been the same as that observed by Lawes and Gilbert for fattening cattle—viz, 73.89—the gains of organic matter recorded in Table X are equivalent to a gain in weight of 1.275 kgm. (2.8 pounds) per day in period 2 and 0.979 kgm. (2.2 pounds) in period 3. The experimental periods were too short to permit very satisfactory conclusions to be drawn from the live weights of the animals. Those weights, taken at about 7 a. m., after the morning feeding and before the daily watering, are shown in the accompanying graph (fig. 1). The straight lines in periods 2 and 3 represent the rates of gain, as computed above, which appear to correspond fairly well with the observed weights. The averages of the last six weighings for each period were as follows:

Period 1.....	490 kgm.
Period 2.....	536 kgm.
Period 3.....	655 kgm.
Period 4.....	642 kgm.

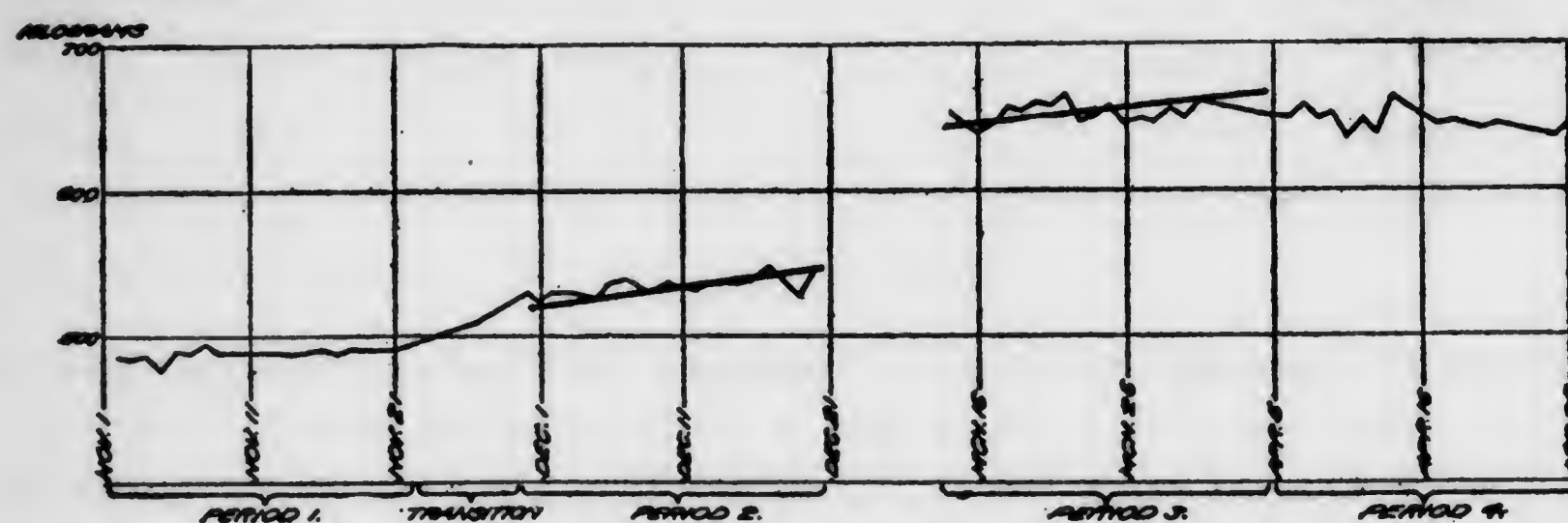


FIG. 1.—Graph of the fluctuations in the live weight of the steer.

A comparison of these estimated gains in weight with the feed consumption yields the results of Table XI. Obviously no great accuracy can be claimed for these computations, but nevertheless they show clearly a decreasing efficiency of the total feed.

TABLE XI.—Feed consumed per unit of estimated gain in weight

Period No.	Total feed.	Dry matter.	Digestible organic matter.
2.....	8.2	7.2	5.2
3.....	11.6	10.1	9.6

HEAT EMISSION AND PRODUCTION.

The measured emission of heat by the animal in the several periods and subperiods is recorded in Table 6 of the Appendix. In the periods on the heavier rations, both in the unfattened and fattened state, a notably larger proportion of the additional heat produced by the animal was disposed of by the evaporation of water, as appears from Table XII.

TABLE XII.—Paths of heat emission

Period No.	Radiation and conduction.	Latent heat of water vapor.
	<i>Per cent.</i>	<i>Per cent.</i>
1.....	75.88	24.12
2.....	52.41	47.59
3.....	54.23	45.77
4.....	68.27	31.73

Applying to the figures for heat emission the necessary corrections for the gain or loss of matter by the body and for the fluctuations of body temperature yields the results for heat production contained in Table 8 of the Appendix, while, in order to render the several periods comparable, a further correction to uniform standing and lying must be made, the corrected results being recorded in Table 9. The average daily heat production of the animal, corrected to a uniform period of 12 hours standing and 12 hours lying, as in our earlier experiments, was:

Period 1.....	10,905 Calories.
Period 2.....	16,511 Calories.
Period 3.....	19,992 Calories.
Period 4.....	14,095 Calories.

ENERGY EXPENDITURE CONSEQUENT ON FEED CONSUMPTION

The foregoing results show the same marked increase in heat production which has been uniformly found to follow an increase in the ration. From a quantitative comparison of the corresponding periods the energy expenditure per unit of total feed (hay and concentrates) consumed may be computed in the case of the unfattened and fattened animal, respectively. The results of this computation are contained in Table XIII. For the reasons stated in a previous paper (2, p. 471) no attempt has been made to correct these results for the differences in live weight.

TABLE XIII.—Energy expenditure per kilogram of dry matter of total ration

Condition and period No.	Dry matter eaten.	Heat production.
	<i>Grams.</i>	<i>Calories.</i>
Unfattened:		
Period 2.....	9,146.3	16,511
Period 1.....	4,462.9	10,905
Difference.....	4,683.4	5,606
Difference per kilogram of dry matter.....		1,197
Fattened:		
Period 3.....	9,911.6	19,992
Period 4.....	5,215.6	14,095
Difference.....	4,696.0	5,897
Difference per kilogram of dry matter.....		1,256

The results are of quite the same order of magnitude as those obtained in previous experiments on similar mixed rations of hay and grain (2, p. 477; 4, p. 385). In the fattened animal there appears to have been an increase of about 5 per cent in the energy expended in the various processes intermediate between the prehension of the feed and the storage of protein and fat in the tissues. To this extent the experiment sustains the view outlined in the introductory paragraphs. The difference, however, is small and it is perhaps questionable whether it exceeds the experimental error. At any rate, it is far from accounting for the very marked difference in the economic utilization of the feed which is indicated by the approximate calculation of Table XI, and is of little significance in comparison with another factor to be considered immediately.

The relations shown in Table XIII may also be expressed in another way by comparing the percentages of the metabolizable energy which were recovered in the gain made in the unfattened and fattened states, respectively, as shown by the energy balances (Table XIV).

TABLE XIV.—Percentage of metabolizable energy recovered in gain

Condition and period No.	Metabolizable energy.	Body gain.	Percentage recovered.
	Calories.	Calories.	
Unfattened:			
Period 2.....	25,398	8,887	.....
Period 1.....	12,269	1,364	.....
Difference.....	13,129	7,523	57.3
Fattened:			
Period 3.....	27,865	7,873	.....
Period 4.....	14,338	243	.....
Difference.....	13,527	7,630	56.4

The foregoing results accord with those recently reported by Moulton (8), who computes from the results of comparative slaughter tests that in a fat and a very fat steer 53.39 per cent and 52.49 per cent, respectively, of the metabolizable energy supplied in excess of maintenance was recovered in the gain.

MAINTENANCE REQUIREMENT

The comparisons of Table XIII also afford data for computing the fasting katabolism of the steer in the manner described in an earlier publication (3, p. 53).

Each kilogram of dry matter consumed increased the katabolism by 1,197 Calories in the unfattened and by 1,256 Calories in the fattened state. It may be computed, therefore, by how much the katabolism would have been reduced had the feed been entirely withdrawn, while

subtracting this amount from the observed heat production will give the basal katabolism. The calculations for periods 1 and 4 are:

$$\begin{aligned}\text{Period 1 (unfattened), } & 10,905 - (1,197 \times 4.4629) = 5,563 \text{ Calories.} \\ \text{Period 4 (fattened), } & 14,095 - (1,256 \times 5.2156) = 7,544 \text{ Calories.}\end{aligned}$$

Similar computations for periods 2 and 3 would, of course, yield the same results.

The results per head and also those computed from the averages of the weights reported on p. 458 to a uniform live weight of 1,000 pounds for the sake of comparison with other data are shown in Table XV.

TABLE XV.—Computed basal katabolism per day

Condition.	Per head.	Per 1,000 pounds, live weight.	
		In proportion to weight.	In proportion to two-thirds power of weight.
	Calories.	Calories.	Calories.
Unfattened.....	5,563	4,919	5,125
Fattened.....	7,544	5,275	5,943

In the unfattened state the animal had a rather low basal katabolism, the average of 23 similar determinations by the writers (1, p. 289) being 5,906 Calories per 1,000 pounds, as compared with 5,125 Calories in this case.

It is evident that the major factor determining the lower economic efficiency in the fattened state was the very marked increase (36 per cent) in the basal katabolism. Doubtless this increase was due in part to the greater body weight to be supported while standing; but, as the table shows, the katabolism increased more rapidly than the weight or the body surface as estimated by the Meek formula. Apparently the accumulation of fat tended in some way to stimulate the general metabolism. These results are quite in harmony with those obtained by Kellner and Köhler (6; 7, p. 14) in experiments on the same subject. This greater maintenance requirement, together with the relatively somewhat smaller feed consumption, was chiefly responsible for the more expensive gains by the fattened animal.

NET ENERGY VALUES

From the foregoing the net energy values of the rations may also be computed as shown in Table XVI.

TABLE XVI.—*Net energy values of total rations per kilogram of dry matter*

	Gross energy (Table IX).	Losses in excreta (Table IX).	Heat increment (Table XIII).	Net energy value.
	Calories.	Calories.	Calories.	Calories.
Period 1.....	4,488	1,739	1,197	1,552
Period 2.....	4,470	1,693		1,580
Period 3.....	4,481	1,670	1,256	1,555
Period 4.....	4,478	1,728		1,494
Average for light rations.....	4,483	1,733	1,227	1,523
Average for heavy rations.....	4,476	1,682	1,227	1,507
Average in unfattened condition.....	4,479	1,716	1,197	1,566
Average in fattened condition.....	4,480	1,699	1,256	1,525

On the average of the experiments of the previous year on the same animal 1 kgm. of dry matter of the alfalfa hay increased the heat production of the animal by 1,018 Calories. If the values for the hay are assumed to be the same as those found in the previous year's experiment, the net energy values of the mixture of concentrates may also be computed as in Tables XVII and XVIII. Obviously this method of computation ascribes the entire difference between the results in the several periods to the concentrates and therefore tends to exaggerate it relatively.

TABLE XVII.—*Computed energy expenditure per kilogram of dry matter of concentrates*

Period No.	Dry matter eaten.		Total heat production.
	Hay.	Concentrates.	
	Gm.	Gm.	Calories.
Period 2.....	3,088.4	6,057.9	16,511
Period 1.....	1,507.6	2,955.3	10,905
Difference.....	1,580.8	3,102.6	5,606
Difference due to hay.....			1,609
Differences due to concentrates.....			3,997
Difference per kilogram of concentrates.....			1,288
Period 3.....	3,335.1	6,576.5	19,992
Period 4.....	1,754.3	3,461.3	14,095
Difference.....	1,580.8	3,115.2	5,897
Difference due to hay.....			1,609
Difference due to concentrates.....			4,288
Difference per kilogram of concentrates.....			1,376

TABLE XVIII.—*Computed net energy values of concentrates per kilogram of dry matter*

Period No.	Gross energy (Table IX).	Losses in excreta (Table IX).	Heat increment (Table XVII).	Net energy value.
	Calories.	Calories.	Calories.	Calories.
Period 1.....	4,562	1,401	1,288	1,873
Period 2.....	4,537	1,334		1,915
Period 3.....	4,554	1,300	1,376	1,878
Period 4.....	4,548	1,389		1,783
Average for light rations.....	4,555	1,395	1,332	1,828
Average for heavy rations.....	4,546	1,317	1,332	1,897
Average in unfattened condition.....	4,550	1,368	1,288	1,894
Average in fattened condition.....	4,551	1,345	1,376	1,830

SUMMARY

(1) A steer in medium condition received, in two successive periods, an approximate maintenance ration and a fattening ration of the same standard mixture of hay and concentrates. The animal was then fattened and the comparison of a maintenance ration and a fattening ration of the same standard feed mixture was repeated.

(2) The digestibility of the lighter ration was in both cases greater than that of the heavier one, although the difference was less than has usually been found in such comparisons.

(3) The corresponding rations were digested equally well by the fattened and unfattened animal.

(4) The relative losses of nitrogen, carbon, and energy in the urine were less on the heavy than on the light rations and a little greater in the fattened than in the unfattened state.

(5) The production of combustible gases (methane), both as compared with the total feed and with the digestible carbohydrates, was notably less on the heavier than on the lighter rations. There was no distinct difference in this respect between the fattened and the unfattened states.

(6) In consequence of the smaller losses in the urine, and especially in the combustible gases, the percentage of the gross energy of the feed which was metabolizable was greater in the heavier than in the lighter rations. No difference in this respect was observed between the fattened and the unfattened animal.

(7) By far the larger share of the additional heat produced on the heavier rations was eliminated by means of evaporation of water.

(8) The heat increment resulting from the consumption of a unit of feed was but little greater in the fattened than in the unfattened condition. Consequently the net energy values of the feed and the percentages of the metabolizable energy which were available for gain were but slightly less in the fattened than in the unfattened condition.

(9) The maintenance requirement of the steer was increased 36 per cent by a 3 months' fattening in which the live weight was increased by about 300 pounds. This increase was greater than corresponded to the increase in weight or in computed body surface.

(10) The lower economic efficiency of the fattened animal in this experiment was due chiefly to his higher maintenance requirement and only to a small extent if at all to a difference in the utilization of the surplus of feed over the maintenance requirement.

LITERATURE CITED

- (1) ARMSBY, H. P.
1917. THE NUTRITION OF FARM ANIMALS. 743 p., 44 fig. New York.
- (2) ——— and FRIES, J. A.
1915. NET ENERGY VALUES OF FEEDING STUFFS FOR CATTLE. *In Jour. Agr. Research*, v. 3, no. 6, p. 435-491, 2 fig. Literature cited, p. 489-491.
- (3) ———
1911. THE INFLUENCE OF TYPE AND OF AGE UPON THE UTILIZATION OF FEED BY CATTLE. U. S. Dept. Agr. Bur. Anim. Indus. Bul. 128, 245 p., 17 fig., 3 pl.
- (4) ——— and BRAMAN, W. W.
1916. ENERGY VALUES OF RED-CLOVER HAY AND MAIZE MEAL. *In Jour. Agr. Research*, v. 7, no. 9, p. 379-387.
- (5) FRIES, J. A.
[1912] THE COMBUSTIBLE GASES EXCRETED BY CATTLE. *In Orig. Commun.* 8th Internat. Cong. Appl. Chem., v. 15, p. 109-119.
- (6) KELLNER, O., and KÖHLER, A.
1898. UNTERSUCHUNGEN ÜBER DEN NAHRUNGS- UND ENERGIE-BEDARF VOLL-JÄHRIGER GEMÄSTETER OCHSEN. *In Landw. Vers. Stat.*, Bd. 50, Heft 3/4, p. 245-296.
- (7) ———
1900. UNTERSUCHUNGEN ÜBER DEN STOFF- UND ENERGIEUMSATZ DES ERWACHSENEN RINDES BEI ERHALTUNGS- UND PRODUKTIONSFUTTER. *Landw. Vers. Stat.*, Bd. 53, 474 p.
- (8) MOULTON, C. R.
1917. THE AVAILABILITY OF THE ENERGY OF FOOD FOR GROWTH. *In Jour. Biol. Chem.*, v. 31, no. 2, p. 389-394.

APPENDIX

The principal numerical data obtained in the experiments are recorded in the following tables. The computations involved have been carried out beyond the probable limit of accuracy of the experimental methods in order to guard against a possible accumulation of arithmetical errors.

COMPOSITION OF FEEDING STUFFS

The alfalfa hay used was taken from a stock of cut hay prepared in 1911-12 for an experiment of that year and again used in an experiment in 1912-13. The hay was old and rather hard, but was well eaten, except in period 3. Enough maize meal for two periods was freshly ground at the beginning of the first and third periods, respectively. The bran and cottonseed meal were purchased from the Dairy Husbandry Department. All the feeds were safely stored and protected from vermin.

The protein and nonprotein content of the feeding stuffs was computed from the nitrogen, using the following factors:

For protein:	
Alfalfa hay.....	6.25
Wheat bran.....	5.70
Maize meal.....	6.0
Cottonseed meal.....	5.5
For nonprotein.....	4.7

TABLE 1.—Composition of dry matter of feeding stuffs

Feed and period.	Ash.	Protein.	Non-protein.	Crude fiber.	Nitrogen-free extract.	Ether extract.	Total nitrogen.	Carbon.	Heat of combustion per kilogram.
Alfalfa hay:	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Calories.</i>
Period 1.....	9.66	12.13	3.01	29.60	43.59	2.01	2.58	45.04	4,344
Period 2.....	9.11	11.34	3.02	32.31	42.41	1.81	2.46	45.12	4,340
Periods 3 and 4.....	9.49	11.85	3.05	30.30	43.04	2.27	2.54	45.16	4,339
Average.....	9.42	11.77	3.03	30.74	43.01	2.03	2.53	45.11	4,341
Average of 3 samples, 1911-12.....	9.06	12.39	2.86	30.10	43.63	1.96	2.59	44.98	4,368
Average of 7 samples, 1912-13.....	9.26	11.29	3.14	30.46	44.09	1.76	2.47	44.90	4,350
Wheat bran:									
Period 1.....	6.54	14.91	1.48	9.70	62.64	4.73	2.93	45.85	4,597
Period 2.....	6.44	14.52	1.92	10.09	62.22	4.81	2.96	45.98	4,587
Periods 3 and 4.....	6.50	14.56	1.80	9.77	62.23	5.14	2.94	45.93	4,573
Average.....	6.49	14.67	1.73	9.85	62.37	4.89	2.94	45.92	4,586
Maize meal:									
Period 1.....	1.53	9.40	.22	2.36	82.16	4.33	1.61	46.22	4,488
Period 2.....	1.44	9.46	.25	2.27	82.35	4.23	1.63	45.74	4,457
Periods 3 and 4.....	1.49	9.56	.22	2.01	82.50	4.22	1.64	45.97	4,465
Average.....	1.49	9.47	.23	2.21	82.34	4.26	1.63	45.98	4,470
Cottonseed meal:									
Period 1.....	6.52	33.43	1.87	12.72	37.32	8.14	6.48	48.11	4,917
Period 2.....	6.37	33.30	2.22	12.31	37.70	8.10	6.53	47.99	4,904
Periods 3 and 4.....	7.41	34.77	2.86	9.48	36.81	8.67	6.93	48.19	4,969
Average.....	6.77	33.83	2.32	11.50	37.28	8.30	6.65	48.10	4,930

DIGESTIBILITY OF RATIONS

The digestibility of the rations was determined in the usual manner. In period 3 residues of mixed hay and grain were left uneaten. In the computation it is assumed that the proportions of the different feeding stuffs in the residues were the same as in the original ration, the actual composition of the residues agreeing closely with that computed on this assumption. The digestibility of the single feeding stuffs was not determined.

TABLE 2.—Digestibility of rations

Period and feed.	Dry matter.	Ash.	Organic matter.	Protein.	Non-protein.	Crude fiber.
Period 1:	Gm.	Gm.	Gm.	Gm.	Gm.	Gm.
Alfalfa hay.....	1,507.6	145.7	1,361.9	182.8	45.3	446.2
Cottonseed meal.....	343.8	22.4	321.4	114.9	6.4	43.7
Wheat bran.....	647.5	42.3	605.3	96.5	9.6	62.8
Maize meal.....	1,964.0	30.0	1,934.0	184.7	4.2	46.3
Total fed.....	4,462.9	240.4	4,222.5	578.9	65.5	599.0
Feces.....	1,054.5	130.1	924.4	141.1	24.6	340.5
Digested.....	3,408.4	110.3	3,298.1	437.8	40.9	258.5
Per cent digested.....	76.37	45.88	78.11	75.63	62.44	43.16
Period 2:						
Alfalfa hay.....	3,088.4	281.4	2,807.0	350.2	93.3	997.8
Cottonseed meal.....	696.2	44.4	651.8	231.9	15.5	85.7
Wheat bran.....	1,342.8	86.5	1,256.3	194.9	25.8	135.4
Maize meal.....	4,018.9	57.7	3,961.2	380.3	10.0	91.1
Total fed.....	9,146.3	470.0	8,676.3	1,157.3	144.6	1,310.0
Feces.....	2,358.7	269.6	2,089.1	328.2	58.1	719.9
Digested.....	6,787.6	200.4	6,587.2	829.1	86.5	590.1
Per cent digested.....	74.21	42.64	75.92	71.64	59.82	45.05
Period 3:						
Alfalfa hay.....	3,508.1	333.0	3,175.1	415.7	106.9	1,063.1
Cottonseed meal.....	813.3	60.3	753.0	282.8	23.2	77.1
Wheat bran.....	1,540.0	100.0	1,440.0	224.2	27.7	150.5
Maize meal.....	4,569.3	68.3	4,501.0	436.7	10.1	91.7
Total fed.....	10,430.7	561.6	9,869.1	1,359.4	167.9	1,382.4
Refused.....	519.1	37.2	481.9	67.7	8.4	77.3
Total eaten.....	9,911.6	524.4	9,387.2	1,291.7	159.5	1,305.1
Feces.....	2,497.4	280.4	2,217.0	311.3	122.5	764.9
Digested.....	7,414.2	244.0	7,170.2	980.4	37.0	540.2
Per cent digested.....	74.80	46.53	76.38	75.90	23.20	41.39
Period 4:						
Alfalfa hay.....	1,754.3	166.5	1,587.8	207.9	53.4	531.6
Cottonseed meal.....	406.6	30.1	376.5	141.4	11.6	38.5
Wheat bran.....	770.0	50.0	720.0	112.1	13.9	75.3
Maize meal.....	2,284.7	34.2	2,250.5	218.4	5.0	45.9
Total fed.....	5,215.6	280.8	4,934.8	679.8	83.9	691.3
Feces.....	1,215.4	135.7	1,079.7	164.9	27.1	394.8
Digested.....	4,000.2	145.1	3,855.1	514.9	56.8	296.5
Per cent digested.....	76.70	51.67	78.12	75.74	67.70	42.89

TABLE 2.—Digestibility of rations—Continued

Period and feed.	N.-free extract.	Ether extract.	Total nitrogen.	Carbon.	Energy.
Period 1:	Gm.	Gm.	Gm.	Gm.	Calories.
Alfalfa hay.....	657.2	30.3	38.9	679.1	6,549.35
Cottonseed meal.....	128.3	28.0	22.3	165.4	1,690.39
Wheat bran.....	405.6	30.6	19.0	296.9	2,976.70
Maize meal.....	1,613.7	85.1	31.7	907.7	8,813.63
Total fed.....	2,804.8	174.0	111.9	2,049.1	20,030.07
Feces.....	400.1	30.9	27.8	488.6	4,895.44
Digested.....	2,404.7	143.1	84.1	1,560.5	15,134.63
Per cent digested.....	85.74	82.24	75.16	76.16	75.56
Period 2:					
Alfalfa hay.....	1,309.7	56.0	75.9	1,393.6	13,402.54
Cottonseed meal.....	262.4	56.4	45.4	334.1	3,414.42
Wheat bran.....	835.6	64.5	39.7	617.4	6,159.01
Maize meal.....	3,309.7	170.1	65.5	1,838.0	17,910.55
Total fed.....	5,717.4	347.0	226.5	4,183.1	40,886.52
Feces.....	940.2	70.8	64.9	1,086.8	10,879.01
Digested.....	4,777.2	276.2	161.6	3,096.3	30,007.51
Per cent digested.....	83.56	79.60	71.35	74.02	73.39
Period 3:					
Alfalfa hay.....	1,509.6	79.8	89.2	1,584.1	15,220.3
Cottonseed meal.....	299.4	70.5	56.4	391.9	4,041.3
Wheat bran.....	958.3	79.2	45.2	707.3	7,042.4
Maize meal.....	3,769.8	192.6	74.9	2,100.5	20,399.8
Total fed.....	6,537.1	422.1	265.7	4,783.8	46,703.8
Refused.....	315.7	12.8	14.1	234.3	2,287.0
Total eaten.....	6,221.4	409.3	251.6	4,549.5	44,416.8
Feces.....	997.3	64.1	75.9	1,156.2	11,494.1
Digested.....	5,224.1	345.2	175.7	3,393.3	32,922.7
Per cent digested.....	83.96	84.34	69.83	74.59	74.12
Period 4:					
Alfalfa hay.....	754.9	39.9	44.6	792.2	7,611.2
Cottonseed meal.....	149.7	35.2	28.2	195.9	2,020.4
Wheat bran.....	479.2	39.6	22.6	353.7	3,521.2
Maize meal.....	1,884.9	96.3	37.5	1,050.3	10,200.1
Total fed.....	3,268.7	211.0	132.9	2,392.1	23,352.9
Feces.....	465.8	38.4	32.2	571.0	5,704.0
Digested.....	2,802.9	172.6	100.7	1,821.1	17,648.9
Per cent digested.....	85.75	81.80	75.77	76.13	75.57

URINARY EXCRETION

The collection was made with a urine funnel in the usual manner. There were occasional losses which were taken up with distilled water and weighed and analyzed separately. The weights given in the Table 3 include the water used to rinse out the urine funnel and tube. There is a

slight uncertainty as to the results in period 2, owing to the fact that some of the spilled urine soaked into the mat, and this amount had to be estimated.

TABLE 3.—Results on urine

Period.	Weight.	Average specific gravity.	Total solids.		Total nitrogen.		Total carbon.		Energy.	
			Per cent.	Gm.	Per cent.	Gm.	Per cent.	Gm.	Per gram.	Total.
Period 1:	Gm.		Per cent.	Gm.	Per cent.	Gm.	Per cent.	Gm.	Small calories.	Large calories.
Collected.....	59,594.0	1.0332	5.399	3,217.5	1.315	783.70	1.779	1,060.2	168.11	10,018.3
Spilled.....	810.0			45.0	1.354	11.0		14.8		140.2
Total, 10 days..	60,404.0			3,262.5		794.7		1,075.0		10,158.5
Average.....	6,040.4			326.3		79.5		107.5		1,015.9
Period 2:										
Collected.....	96,277.0	1.0364	5.597	5,388.6	1.434	1,380.3	1.970	1,896.7	176.04	16,948.6
Spilled.....	2,268.0			54.7		14.0		19.2		171.9
Total, 10 days..	98,545.0			5,443.3		1,394.3		1,915.9		17,120.5
Average.....	9,854.5			544.3		139.4		191.6		1,712.1
Period 3:										
Collected.....	75,120.0	1.034	6.560	5,379.5	1.549	1,163.8	1.996	1,636.8	186.55	15,298.0
Spilled.....	5,506.0			375.8		81.3		114.3		1,068.7
Total, 8 days..	80,626.0			5,755.3		1,245.1		1,751.1		16,366.7
Average.....	10,078.3			719.4		155.6		218.9		2,045.8
Period 4:										
Collected, 10 days	82,960.0	1.031	4.950	4,106.5	1.289	1,069.6	1.641	1,361.4	158.97	13,188.2
Average.....	8,296.0			410.7		107.0		136.1		1,318.8

EPIDERMAL TISSUE

The steer was thoroughly brushed before entering the calorimeter and again after leaving it. The hair and dandruff obtained in the second brushing and the small amounts swept up in the calorimeter were weighed and their content of nitrogen, carbon, and energy determined. The steer was clipped at the beginning of the experiment and at its close, 185 days later, and the same determinations made upon the hair obtained in the second clipping. The total of hair and brushings is regarded as representing the production of epidermal tissue (Table 4).

TABLE 4.—Average daily production of epidermal tissue

Factor.	In growth of hair.	In brushings.	Total.
Dry matter.....gm..	2.6	23.7	26.3
Nitrogen.....gm..	.4	1.8	2.2
Carbon.....gm..	1.3	9.6	10.9
Energy.....cal..	14.2	104.5	118.7

GASEOUS EXCRETION

The excretion of carbon dioxide and methane, the latter being computed from the total carbon found in the combustible gases, is given in table 5:

TABLE 5.—Gaseous excretion

Period.	Water.	Carbon dioxide.	In combustible gases.		Methane computed from carbon.	Ratio, hydrogen to carbon.
			Hydrogen.	Carbon.		
Period 1:	Gm.	Gm.	Gm.	Gm.	Gm.	1:
Subperiod 1.....	2,320.90	2,305.76	16.58	47.39	63.32	2.858
Subperiod 2.....	2,173.04	2,310.16	17.27	51.93	69.39	3.007
First day.....	4,493.94	4,615.92	33.85	99.32	132.71	2.934
Subperiod 3.....	2,257.43	2,301.85	17.78	53.04	70.88	2.983
Subperiod 4.....	2,234.52	2,350.06	17.53	53.12	70.99	3.030
Second day.....	4,491.95	4,651.91	35.31	106.16	141.87	3.006
Average.....	4,492.95	4,633.92	34.58	102.74	137.29	2.970
Period 2:						
Subperiod 1.....	7,118.08	3,738.82	24.92	76.24	101.88	3.059
Subperiod 2.....	6,550.47	3,820.64	25.97	77.93	104.13	3.001
First day.....	13,668.55	7,559.46	50.89	154.17	206.01	3.029
Subperiod 3.....	6,712.28	3,730.76	25.90	78.60	105.03	3.035
Subperiod 4.....	6,965.47	3,727.53	23.88	75.54	100.94	3.163
Second day.....	13,677.75	7,458.29	49.78	154.14	205.97	3.096
Average.....	13,673.15	7,508.88	50.34	154.16	205.99	3.063
Period 3:						
Subperiod 1.....	5,480.06	4,319.04	24.97	75.05	100.28	3.005
Subperiod 2.....	7,662.40	4,534.97	26.93	81.01	108.25	3.008
First day.....	13,142.46	8,854.01	51.90	156.06	208.53	3.007
Subperiod 3.....	9,998.87	4,614.54	27.46	81.96	109.52	2.985
Subperiod 4 ^a	10,011.85	4,678.52	27.94	84.92	113.48	3.039
Second day.....	20,010.72	9,293.06	55.40	166.88	223.00	3.012
Average.....	16,576.59	9,073.54	53.65	161.47	215.77	3.010
Period 4:						
Subperiod 1.....	3,707.71	2,937.49	19.96	61.04	81.57	3.058
Subperiod 2.....	3,972.70	2,928.18	18.58	55.95	74.76	3.012
First day.....	7,680.41	5,865.67	38.54	116.99	156.33	3.033
Subperiod 3.....	3,924.83	2,963.99	18.77	57.39	76.69	3.058
Subperiod 4.....	3,925.62	2,958.43	18.30	56.14	75.01	3.068
Second day.....	7,850.45	5,922.42	37.07	113.53	151.70	3.063
Average.....	7,765.43	5,894.05	37.81	115.26	154.02	3.048

^a Computed from results for last 6 hours.

HEAT EMISSION

The amounts of heat given off by the animal by radiation and conduction and as latent heat of water vapor are given in Table 6.

TABLE 6.—Heat emission

Period.	By radiation and conduction.	As latent heat of water vapor.	Total.
	Calories.	Calories.	Calories.
Period 1:			
Subperiod 1.....	4, 185. 0	1, 362. 4	5, 547. 4
Subperiod 2.....	4, 182. 3	1, 275. 6	5, 457. 9
First day.....	8, 367. 3	2, 638. 0	11, 005. 3
Subperiod 3.....	4, 177. 7	1, 325. 1	5, 502. 8
Subperiod 4.....	4, 048. 9	1, 311. 7	5, 360. 6
Second day.....	8, 226. 6	2, 636. 8	10, 863. 4
Average.....	8, 297. 0	2, 637. 4	10, 934. 4
Period 2:			
Subperiod 1.....	4, 418. 3	4, 178. 3	8, 596. 6
Subperiod 2.....	4, 433. 2	3, 845. 1	8, 278. 3
First day.....	8, 851. 5	8, 023. 4	16, 874. 9
Subperiod 3.....	4, 795. 2	3, 940. 1	8, 735. 3
Subperiod 4.....	4, 029. 0	4, 088. 7	8, 117. 7
Second day.....	8, 824. 2	8, 028. 8	16, 853. 0
Average.....	8, 837. 9	8, 026. 1	16, 864. 0
Period 3:			
Subperiod 1.....	7, 336. 8	3, 216. 8	10, 553. 6
Subperiod 2.....	5, 765. 0	4, 497. 8	10, 262. 8
First day.....	13, 101. 8	7, 714. 6	20, 816. 4
Subperiod 3.....	5, 007. 1	5, 869. 3	10, 876. 4
Subperiod 4.....	4, 953. 6	5, 877. 7	10, 831. 3
Second day.....	9, 960. 7	11, 747. 0	21, 707. 7
Average.....	11, 531. 3	9, 730. 8	21, 262. 1
Period 4:			
Subperiod 1.....	4, 725. 0	2, 176. 4	6, 901. 4
Subperiod 2.....	4, 800. 9	2, 332. 0	7, 132. 9
First day.....	9, 525. 9	4, 508. 4	14, 034. 3
Subperiod 3.....	5, 194. 4	2, 303. 9	7, 498. 3
Subperiod 4.....	4, 890. 3	2, 304. 3	7, 194. 6
Second day.....	10, 084. 7	4, 608. 2	14, 692. 9
Average.....	9, 805. 3	4, 558. 3	14, 363. 6

HEAT PRODUCTION

To ascertain the heat production, the measured heat emission as recorded in Table 6, must be corrected for any storage of heat in the body, due either to fluctuations of body temperature or to a gain or loss of matter by the body.

The rectal temperature of the animal was taken after it had stood in the calorimeter for about four hours—that is, about one hour before the beginning of the first subperiod—and again immediately after leaving the calorimeter. It would appear probable that the former temperature may be taken without serious error as the body temperature at the beginning of the experiment. Table 7 shows the body temperatures as taken and likewise the live weights of the animal when leaving the calorimeter.

TABLE 7.—Body temperatures and live weights

Period No.	Temperature.			Live weight when leaving calorimeter.
	Entering.	Leaving.	Difference.	
	°C.	°C.	°C.	Kgm.
1.....	38. 8	38. 2	—0. 6	493
2.....	38. 7	38. 9	+0. 2	542
3.....	39. 0	39. 3	+0. 3	664
4.....	38. 7	38. 6	—0. 1	642

If the specific heat of the body is assumed to be 0.8, the corresponding correction to be applied to the heat emission, computed on the live weight when leaving the calorimeter, would be as shown in the second column of Table 8. The correction for the gain or loss of matter by the body is based on the observed gain or loss of protein, fat, and water and has been computed in the manner described in a previous paper (1).

Applying these corrections gives the results recorded in Table 8 for the heat production as compared with that computed in the usual way from the balance of nitrogen and carbon.

CORRECTION TO UNIFORM STANDING AND LYING

The proportion of time spent in the standing and lying positions, respectively, during the respiration calorimeter trials varied considerably, the percentage lying ranging, on the single days, from 26.7 to 58.4, equivalent, respectively, to 384.5 minutes and 840.5 minutes per 24 hours. The corresponding range for the entire 48-hour periods was 773 to 1,662 minutes per 48 hours, or from 26.8 to 57.7 per cent. In order to render the several periods comparable, the heat production has been computed to 12 hours standing and 12 hours lying, respectively, by the method described in a previous publication (2, p. 454).

TABLE 8.—Heat production

Period.	Heat emission.	Correction for body temperature.	Correction for body gain per day.	Observed heat production.	Computed heat production.	Computed + observed.
Period 1:	<i>Calories.</i>	<i>Calories.</i>	<i>Calories.</i>	<i>Calories.</i>	<i>Calories.</i>	<i>Per cent</i>
First day.....	11,005.3	.....	- 53.5	10,951.8	11,198.2	102.3
Second day.....	10,863.4	.....	- 21.7	10,841.7	11,283.5	104.1
Average, corrected for body temperature...	10,934.4	-236.6	- 37.6	10,660.2	11,240.9	105.4
Period 2:						
First day.....	16,874.9	.....	-165.2	16,709.7	17,106.7	102.4
Second day.....	16,853.0	.....	-219.4	16,633.6	16,762.8	100.8
Average, corrected for body temperature...	16,864.0	+ 86.7	-192.3	16,758.4	16,934.8	101.1
Period 3:						
First day.....	20,816.4	.....	+104.1	20,920.5	20,702.4	99.0
Second day.....	21,707.7	.....	-218.3	21,489.4	22,129.6	103.0
Average, corrected for body temperature...	21,262.1	+159.4	- 57.1	21,364.4	21,416.0	100.2
Period 4:						
First day.....	14,034.3	.....	-156.5	13,877.8	14,611.2	105.3
Second day.....	14,692.9	.....	-121.9	14,571.0	14,820.8	101.0
Average, corrected for body temperature...	14,363.6	- 51.4	-139.2	14,173.0	14,716.0	103.8

TABLE 9.—Daily heat production computed to 12 hours each standing and lying

Period No.	First day.	Second day.	Average for 48 hours corrected for body temperature.
	<i>Calories.</i>	<i>Calories.</i>	<i>Calories.</i>
1.....	11,146.2	11,135.7	10,904.5
2.....	16,972.1	15,720.8	16,510.6
3.....	19,550.9	20,117.0	19,991.8
4.....	14,277.1	14,151.2	14,094.8

A.—The steer before fattening
B.—The steer after fattening.

PLATE 41

Fatness of Cattle and Feed Utilization

PLATE 41



Journal of Agricultural Research

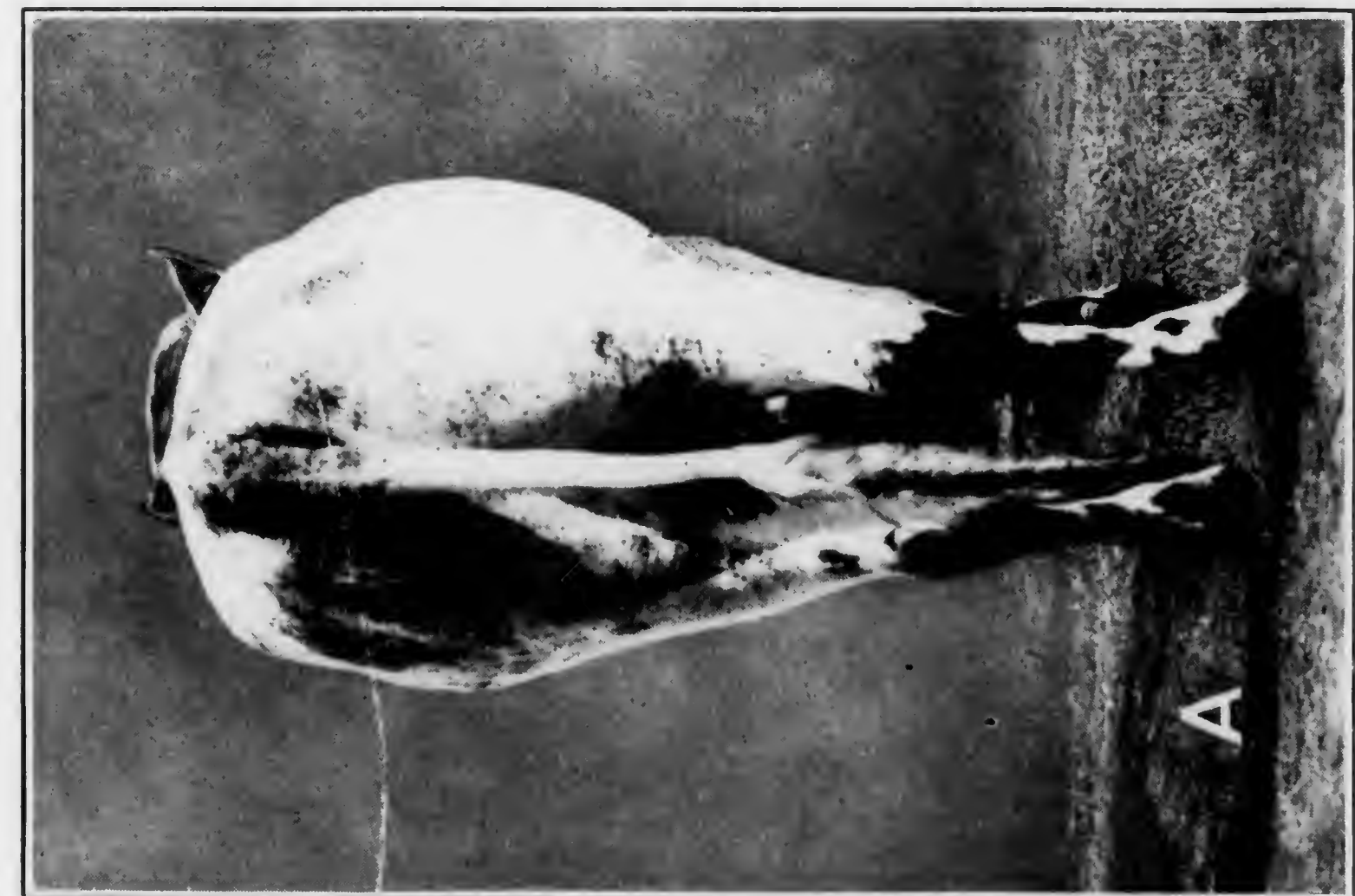
Vol. XI, No. 10

A.—The steer before fattening
B.—The steer after fattening.

PLATE 41

Fatness of Cattle and Feed Utilization

PLATE 41



Journal of Agricultural Research

Vol. XI, No. 10

INTENTIONAL SECOND EXPOSURE

THE BASAL KATABOLISM OF CATTLE AND OTHER SPECIES

BY HENRY PRENTISS ARMSBY, J. AUGUST FRIES AND WINFRED WAITE
BRAMAN

INSTITUTE OF ANIMAL NUTRITION, THE PENNSYLVANIA STATE COLLEGE

Communicated by R. Pearl, December 13, 191

The basal katabolism of herbivora and especially of ruminants, unlike that of man or carnivora, cannot well be measured in the fasting state on account of the relatively large amount of feed always present in the alimentary canal of the former species. It may, however, be determined indirectly in the manner described by the authors^{1,2,3} by measuring the total metabolism upon two different amounts of the same ration and from these data computing the level to which the metabolism would be reduced were all feed withdrawn. For example, a steer receiving two different amounts of the same mixed ration gave the following results:

	DRY MATTER EATEN DAILY	DAILY HEAT PRODUCTION
	<i>kgms.</i>	<i>calories</i>
Period 2.....	9.146	16,511
Period 1.....	4.463	10,905
Difference.....	4.683	5,606
Heat increment per kilogram of dry matter.....		1,197

Evidently, out of the total metabolism of 10905 Calories in Period 1, $1197 \times 4.463 = 5342$ Calories may be regarded as the heat production caused by the 4.463 kgm. of dry matter eaten while the remainder, 5563 Calories is the basal katabolism.

Our investigations upon the metabolism of cattle, which have been published elsewhere³ afford data for computing in the manner just illustrated the basal katabolism of ten unfattened steers in twenty-seven experiments. In view of the very striking effect of standing in increasing the metabolism of cattle the

basal katabolism per 24 hours has been computed separately from the observed rate of heat production during the intervals of lying and standing, respectively, and also for 12 hours standing and 12 hours lying per day, assumed as representing average conditions.

As was to be expected, the basal katabolism increased with the size of the animal but with very considerable fluctuations. The graphs of the results indicate an equally close relation of the basal katabolism with the weight and with the two-thirds power of the weight (computed body surface) and this conclusion is confirmed by a comparison of the coefficients of correlation as follows:

Coefficients of correlation

	WITH LIVE WEIGHT	WITH 2/3 POWER OF LIVE WEIGHT
Basal katabolism, lying 24 hours.....	0.8655 $\pm$ 0.0326	0.9032 $\pm$ 0.0239
Basal katabolism, standing 12 hours.....	0.8733 $\pm$ 0.0308	0.8710 $\pm$ 0.0313
Basal katabolism, standing 24 hours.....	0.8548 $\pm$ 0.0350	0.8250 $\pm$ 0.0415

Computing the basal katabolism per square meter of body surface as estimated by Moulton's formulae⁴ viz.,

For unfattened animals $S = 0.1186 W^{5/8}$

For fattened animals $S = 0.158 W^{5/9}$

the following results were obtained.

Basal katabolism of cattle per square meter of body surface

	LYING 24 HOURS	STANDING 12 HOURS	STANDING 24 HOURS
Mean, Calories.....	964.0	1173.0	1365.0
Probable error of mean, Calories.....	$\pm$ 24.0	$\pm$ 21.4	$\pm$ 25.7
Probable error of single result, Calories.....	$\pm$ 124.8	$\pm$ 110.9	$\pm$ 133.6
Standard deviation, Calories.....	185.1 $\pm$ 17.0	164.5 $\pm$ 15.1	198.0 $\pm$ 18.2
Coefficient of variability.....	0.1920	0.1462	0.1451

A positive correlation of the basal katabolism per square meter body surface with the live weight was also found as follows:

Coefficients of correlation with live weight

Basal katabolism per square meter

Lying 24 hours.....	0.5375 $\pm$ 0.0923
Standing 12 hours.....	0.3666 $\pm$ 0.1124
Standing 24 hours.....	0.2405 $\pm$ 0.1223

The results show the marked influence of standing upon the metabolism of cattle, the mean 24 hour basal katabolism lying, standing 12 hours and standing 24 hours being in the proportion of 100 : 121 : 141, the differences largely exceeding the probable errors. Computing, from the results per square

meter of surface, the basal katabolism for 12 hours standing and 12 hours lying gives as the maintenance requirement for a 1000-pound steer 5918 $\pm$ 560 Calories.

The results for the basal katabolism of man reported by Benedict, Emmes, Roth and Smith,⁵ and by Means⁶ present much the same picture as ours upon cattle with the exception of a much lower variability.

Coefficients of correlation

	WITH BODY WEIGHT	WITH BODY SURFACE
Total basal katabolism		
98 men.....	0.7263 $\pm$ 0.0320	0.7747 $\pm$ 0.0272
75 women.....	0.7759 $\pm$ 0.0310	0.7447 $\pm$ 0.0347

Daily basal katabolism of men and women per square meter of surface

	MEN	WOMEN
Mean Calories.....	830.0	768.0
Probable error of mean, Calories.....	$\pm$ 4.3	$\pm$ 4.9
Probable error of single result, Calories.....	$\pm$ 42.3	$\pm$ 42.8
Standard deviation, Calories.....	62.7 $\pm$ 3.0	63.5 $\pm$ 3.1
Coefficient of variability.....	0.0755	0.0827

Correcting for the error shown by D. and E. F. DuBois⁷ to be incident to the use of the Meeh formula, the means for men and women are as follows:

Corrected daily basal katabolism of men and women per square meter of body surface

	MEN	WOMEN
Means, Calories.....	935.0	886.0
Probable error of mean.....	$\pm$ 4.8	$\pm$ 5.8
Probable error of single result.....	$\pm$ 47.5	$\pm$ 49.4

Including the data obtained by Meissl, Strohmer, and Lorenz⁸ by Tangl⁹ and by Fingerling, Köhler and Reinhardt¹⁰ for swine and by Zuntz and Hagermann¹¹ for the horse, the following comparison of species may be made.

Mean daily basal katabolism per square meter of body surface

Men (complete muscular rest).....	935 $\pm$ 5
Women (complete muscular rest).....	886 $\pm$ 6
Cattle (lying).....	964 $\pm$ 24
Hogs (lying).....	1078 $\pm$?
Horse (standing quietly).....	948 $\pm$?

Considering the nature of the results they show a rather striking degree of uniformity and tend to confirm the conclusions of E. Voit¹² that the basal

katabolism of different species of animals is substantially proportional to their body surface. It may be surmised that the exceptional result with the hog is due to the imperfect data available for computing the body surface of this species.

- ¹ Armsby, Washington, D. C., U. S. Dept. Agric., Bur. Anim. Indust., Bul. 142, 1912.
- ² Armsby and Fries, *Ibid.*, Bul. 128, 1911.
- ³ Armsby and Fries, *J. Agric. Res.*, Washington, 3, 1915, (435); 10, 1917, (599); 11, 1917.
- ⁴ Moulton, *J. Biol. Chem.*, New York, 24, 1916, (299).
- ⁵ Benedict, Emmes, Roth and Smith, *Ibid.*, 18, 1914, (139).
- ⁶ Means, *Ibid.*, 21, 1915, (263).
- ⁷ DuBois and DuBois, *Arch. Inter. Med.*, 15, 1915, (868).
- ⁸ Meissl, Strohmer and Lorenz, *Zs. Biol.*, München 22, 1886, (63).
- ⁹ Tangl, *Biochem. Zs.*, 44, 1912, (252).
- ¹⁰ Fingerling, Köhler and Reinhardt, *Landw. Versuchstat.*, Berlin, 84, 1914, (149).
- ¹¹ Zuntz and Hageman, *Landw. Jahrb.*, Berlin, 27, 1898, Ergzbd. III, (284).
- ¹² Voit, E., *Zs. Biol.*, München, 41, 1901, (113).

BASAL KATABOLISM OF CATTLE AND OTHER SPECIES

By HENRY PRENTISS ARMSBY, *Director*, J. AUGUST FRIES, *Assistant Director*, and WINFRED WAITE BRAMAN, *Associate*, *Institute of Animal Nutrition of The Pennsylvania State College*

COOPERATIVE INVESTIGATIONS BETWEEN THE BUREAU OF ANIMAL INDUSTRY OF THE UNITED STATES DEPARTMENT OF AGRICULTURE AND THE INSTITUTE OF ANIMAL NUTRITION OF THE PENNSYLVANIA STATE COLLEGE

INTRODUCTION

The term "basal katabolism" has become generally accepted as a convenient designation for that portion of the katabolism due to the fundamental vital processes as distinguished, on the one hand, from that arising from external muscular activities and, on the other hand, from that caused by the ingestion of food. It is the katabolism of the animal in a state of complete muscular rest and with the processes of digestion and resorption suspended. It is the irreducible minimum of metabolic activity consistent with a particular condition of the body.

The basal katabolism in this strict sense is to some degree an ideal conception, although a close approach to the ideal may be observed in the postresorptive condition during short periods of complete muscular relaxation. Basal katabolism as thus defined is, from a slightly different point of view, an expression of the minimum food requirement of the organism. Any surplus above this minimum may either be utilized for muscular activity or give rise to a storage of matter and energy.

As regards the necessary food supply, however, a knowledge of the basal katabolism in the strict sense is of limited utility. A state of complete muscular inactivity can not be maintained for any considerable time, while even slight exertion augments the katabolism to a marked degree. In estimating the food requirements for the performance of a given amount of work by man or domestic animals, or for the storage of a specific quantity of protein and fat in the form of meat or milk, the base line is afforded, not by the katabolism during short periods of absolute rest but by the fasting katabolism of the individual under average conditions of living. Particularly is this true of the feeding of domestic animals for the production of human food. The dairy cow or the fattening steer must receive enough feed to supply its incidental daily activities as well as its minimum katabolism in a state of absolute rest before any is permanently available for manufacture into milk or meat. This amount, commonly spoken of as the maintenance requirement, is measured by the fasting katabolism under average conditions and may be called the 24-hour basal katabolism. Obviously, this is not as sharply defined a conception as is the basal katabolism in the narrower sense, but its practical importance is evident.

METHODS OF EXPERIMENTATION

The determination of the fasting katabolism of animals such as Carnivora, man, or swine, having a comparatively simple apparatus, is largely a question of experimental technic. With ruminants the case is different. Their digestive apparatus is capacious and complicated, and contains at all times a relatively large amount of feed in process of digestion. It seems scarcely possible by any moderate period of fasting to reach a condition corresponding to the postresorptive state in man or Carnivora. The fasting katabolism may, however, be obtained indirectly by a comparison of the total metabolism on two different amounts of the same feed in the manner described in previous publications (1, p. 33; 2, p. 282; 3, p. 53; 6, p. 460).¹ For example, a steer receiving two different amounts of the same mixed ration gave the following results:

Item.	Dry matter eaten daily.	Daily heat production.
	Kgm.	Calories.
Period 2.....	9.146	16,511
Period 1.....	4.463	10,905
Difference.....	4.683	5,606
Heat increment per kilogram of dry matter.....		1,197

Evidently, out of the total metabolism of 10,905 Calories in period 1, $1,197 \times 4.463 = 5,342$ Calories may be regarded as the heat production caused by the 4.463 kgm. of dry matter eaten, while the remainder, 5,563 Calories, is the basal katabolism.

Strictly speaking, the foregoing method of computation assumes that the heat production caused by the feed is a linear function of its amount. This can not be regarded as having been proved, but no distinct indications to the contrary have appeared within the range of our experiments, while Wood and Yule (21, p. 239) compute that in Kellner's respiration experiments on fattening cattle the gains expressed in terms of energy are proportional to the metabolizable energy supplied in excess of maintenance, which, of course, is equivalent to saying that the heat production is also a linear function of the feed supply.

Our investigations on the metabolism of cattle afford data for a number of computations of the basal katabolism. Full statements regarding the methods employed, the animals used, the feed consumed, etc., have already been published (4, 5, 6, 7). The designations of the experiments, animals, and periods in the following pages correspond with those in the publications cited.

In view of the very striking effect of standing in increasing the metabolism of cattle the basal katabolism per 24 hours has been computed

¹ Reference is made by number (italic) to "Literature cited," pp. 55-57.

separately from the observed rate of heat production during the intervals of lying and standing, respectively, and also for 12 hours standing and 12 hours lying per day, assumed as representing average conditions (Table I).

TABLE I.—Computed 24-hour basal katabolism of cattle per head

Feeding stuffs.	Experiment No.	Animal No.	Periods compared.	Basal katabolism.			Average live weight.	Approximate age.
				Lying 24 hours.	Standing 12 hours.	Standing 24 hours.		
				Cal.	Cal.	Cal.	Kgm.	Months.
Timothy hay.....	174	I	D-A...	6,136	6,927	7,717	406	36
Red clover hay.....	179	I	1-2....	2,992	6,502	7,006	533	48
Do.....	186	I	2a-1a...	7,509	8,298	9,087	579	60
Do.....	186	I	2b-3b...	8,157	8,828	9,499	571	60
Timothy hay.....	190	A	4-3....	2,963	4,197	5,341	275	11
Do.....	190	B	4-3....	1,979	3,445	3,487	192	13
Do.....	200	A	4-3....	5,395	5,845	6,277	403	23
Do.....	200	B	4-3....	4,143	4,819	5,521	303	25
Do.....	207	A	4-3....	4,489	5,105	5,695	511	35
Do.....	207	B	4-3....	5,226	5,395	5,935	380	37
Alfalfa hay.....	208	D	1-2....	2,449	2,525	2,602	167	9
Do.....	208	E	4-6....	2,274	2,867	3,462	211	9
Alfalfa hay and mixed grain.	208	E	1-3....	2,945	3,742	4,537	204	9
Alfalfa hay.....	208	C	4-6....	2,696	3,759	4,841	282	9
Alfalfa hay and mixed grain.	208	C	2-3....	3,209	4,370	5,532	264	9
Alfalfa hay.....	209	F	4-6....	3,591	4,134	4,679	307	21
Alfalfa hay and mixed grain.	209	F	1-3....	4,015	4,913	5,810	292	21
Maize stover.....	210	D	1-3....	3,647	4,746	5,828	331	21
Mixed hay.....	211	D	1-5....	5,124	6,601	8,066	444	33
Mixed hay and hominy feed.	211	D	3-2....	4,298	5,921	7,531	451	33
Mixed hay.....	211	G	1-5....	4,525	5,818	7,098	377	28
Mixed hay and maize meal.	211	G	3-2....	4,577	5,446	6,403	378	28
Alfalfa hay.....	212	H	1-5....	3,650	4,760	5,551	343	20
Alfalfa meal.....	212	H	2-6....	2,545	3,314	4,142	339	20
Alfalfa hay.....	216	J	5-7....	3,853	5,127	6,342	390	21
Alfalfa hay and starch....	216	J	1-4....	4,560	5,348	6,157	372	21
Alfalfa hay and mixed grain.	217	J	2-1....	4,882	5,563	6,243	513	33
Do.....	217	J	3-4....	6,474	7,544	8,618	649	33

In experiment 217 steer J was fattened previous to periods 3 and 4 with the result of greatly increasing his basal katabolism both per head and per unit of surface (6). The result in these two periods, therefore, does not seem to be comparable with the others and has been omitted in the following comparisons. Steer C had also been full-fed from birth for the production of baby beef, but was by no means so fat as the more mature steer J and has been included in the discussion.

The results of Table I are shown graphically in figures 1, 2, and 3 in which the crosses represent the individual results, the straight lines the mean katabolism computed in proportion to the live weight, and the curves the mean katabolism computed in proportion to the body surface

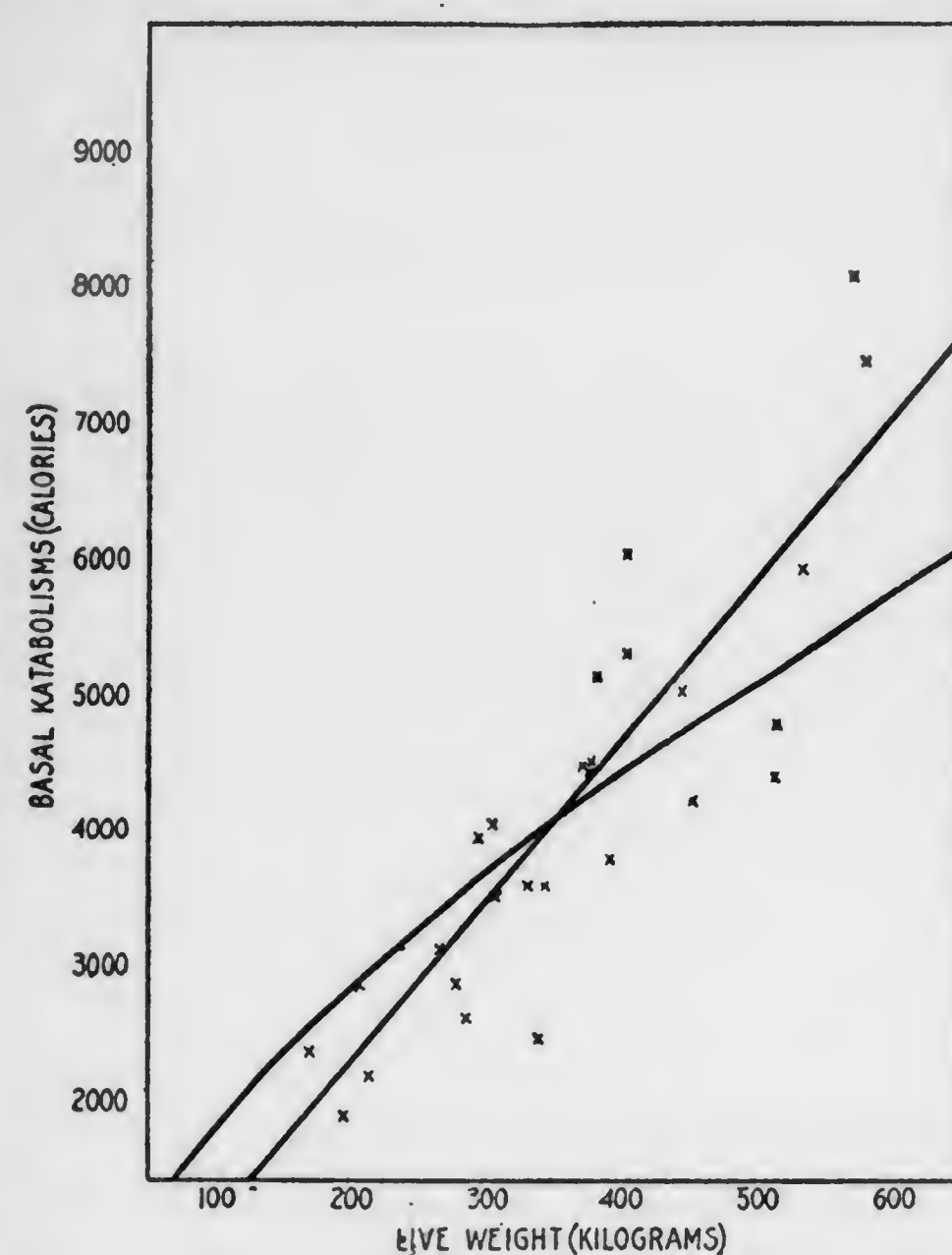


FIG. 1.—Graph of the basal katabolism of cattle per 24 hours' lying.

weight and with the two-thirds power of the live weight has been computed, with the results shown in Table II.

TABLE II.—Coefficients of correlation

	With live weight.	With two-thirds power of live weight.
Basal katabolism, lying 24 hours.	0.8655 ± 0.0326	0.9032 ± 0.0239
Basal katabolism, standing 12 hours.	.8733 ± .0308	.8710 ± .0313
Basal katabolism, standing 24 hours.	.8548 ± .0350	.8250 ± .0415

Rather high coefficients were naturally to be expected, but the results fail to show any closer correlation with the two-thirds power of the weight than with the weight itself, a fact which is in harmony with Benedict's results upon man cited on a subsequent page.

¹ The statistical computations throughout this paper follow the methods described by C. B. Davenport in Chapter II of his "Statistical Methods with Special Reference to Biological Variation." (DAVENPORT, C. B. STATISTICAL METHODS, WITH SPECIAL REFERENCE TO BIOLOGICAL VARIATION. ed. 3, p. 10-18, fig. 4 New York, London, 1914.)

KATABOLISM PER UNIT OF SURFACE

Since, however, as appears from the foregoing comparisons, the body surface affords at least as satisfactory a reference unit as body weight, it seems desirable to follow

the usual practice and compute the basal katabolism per unit of body surface. Such computations have generally been made by means of the formula proposed by Meeh (15)—viz, $S = k W^{\frac{2}{3}}$ in which S equals the body surface in square centimeters, W the body weight in grams and k a constant for the same species. Trowbridge, Moulton, and Haigh (19) have reported the weights and body surfaces of 35 beef steers and have computed the value of k for different classes of beef cattle. Moulton (17) has discussed the data further and has proposed for beef cattle the following modifications of Meeh's formula, which he regards as more accurate, in which W equals the empty weight in kilograms and S the body surface in square meters.

For cattle in thin or medium condition $S = 0.1186 W^{\frac{2}{3}}$
For fat cattle $S = 0.1581 W^{\frac{2}{3}}$

Applying these formulas to the data of Table I, estimating the empty weight at 89 per cent of the live weight in the unfattened animals and 92 per cent in the full-fed steer C and in steer J, gives the results for the basal katabolism per square meter of surface shown in Table III. For steers C and J the formula for fat cattle has been employed.

The results upon steer J in experiment 217, periods 3 and 4, having been omitted as before, the frequency distribution of the remaining 27 results is shown in figures 4, 5, and 6. While the smoothed graphs show more or less divergence from the probability curve, especially for the results per 24 hours' standing, nevertheless, in view of the rather small number of observations, it would seem that the distribution may be regarded as fairly normal, at least in the two other cases. Assuming this,

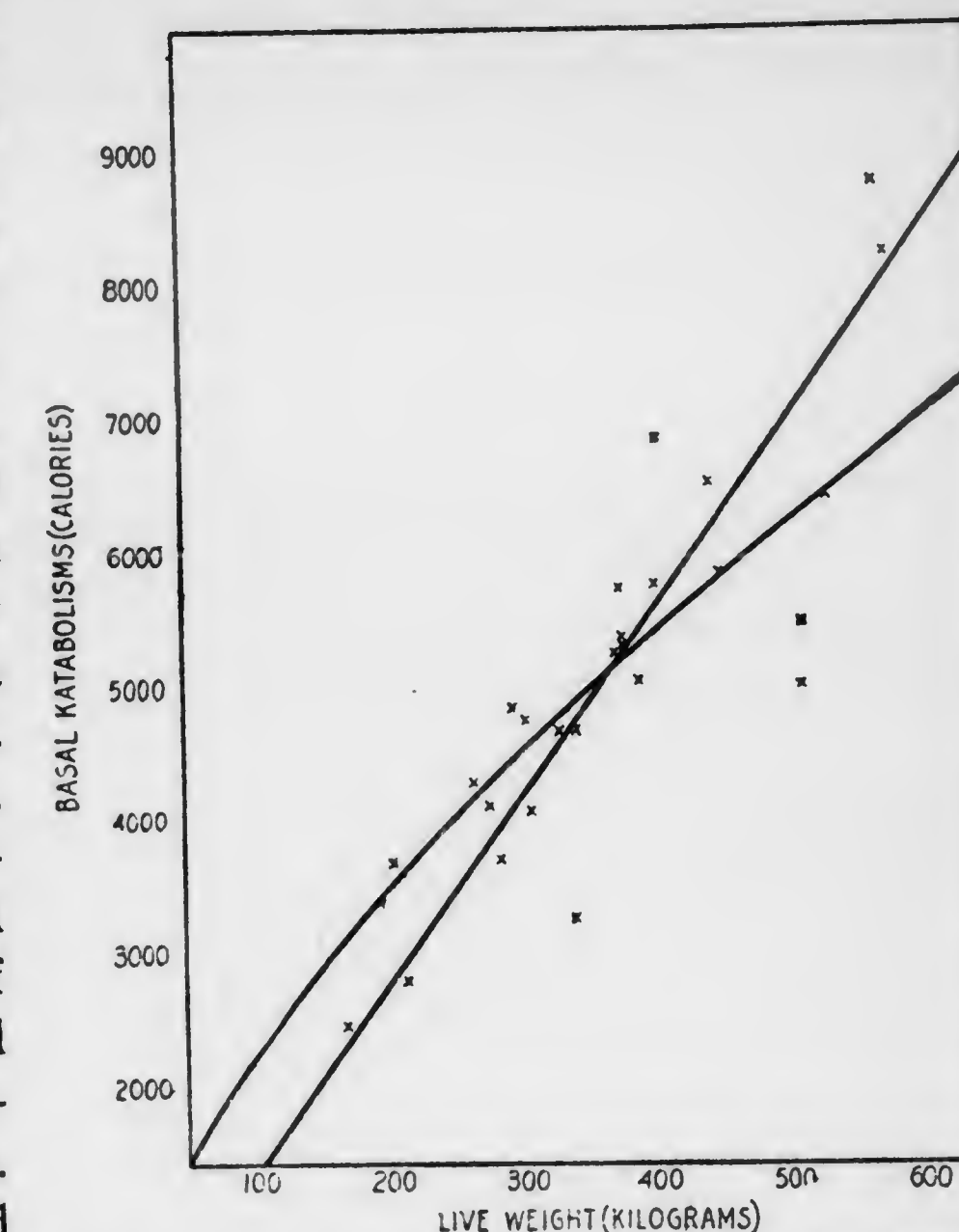


FIG. 2.—Graph of the basal katabolism of cattle per 12 hours' lying and 12 hours' standing.

¹ Erroneously printed as 0.134 in Moulton (17).

the ordinary statistical methods have been applied to the data of Table III, with the results recorded in Table IV. In considering the significance of these results it should be borne in mind that the experiments were upon 10 different animals and that in most instances those upon the same animal were made in different years. How far the factors of individuality and age thus introduced may affect the significance of the statistical calculations is a matter for future investigation. The results are recorded here for what they are worth.

TABLE III.—Computed 24-hours basal katabolism of cattle per square meter of body surface

Feeding stuffs.	Ex- peri- ment No.	Animal No.	Periods com- pared.	Com- puted body surface.	Basal katabolism per square meter of body surface.		
					Lying 24 hours.	Stand- ing 12 hours.	Stand- ing 24 hours.
				Square meters.	Cal.	Cal.	Cal.
Timothy hay.....	174	I	D-A	4.706	1,304	1,472	1,640
Red clover hay.....	179	I	1-2	5.578	1,074	1,166	1,256
Do.....	186	I	2a-1a	5.875	1,278	1,412	1,547
Do.....	186	I	2b-3b	5.825	1,401	1,515	1,631
Timothy hay.....	190	A	4-3	3.693	802	1,136	1,446
Do.....	190	B	4-3	2.949	671	1,168	1,182
Do.....	200	A	4-3	4.690	1,150	1,246	1,338
Do.....	200	B	4-3	3.925	1,056	1,228	1,407
Do.....	207	A	4-3	5.437	826	939	1,047
Do.....	207	B	4-3	4.516	1,157	1,195	1,314
Alfalfa hay.....	208	D	1-2	2.707	905	933	961
Do.....	208	E	4-6	3.129	727	916	1,106
Alfalfa hay and mixed grain.....	208	E	1-3	3.067	960	1,221	1,479
Alfalfa hay.....	208	C	4-6	3.403	779	1,085	1,398
Alfalfa hay and mixed grain.....	208	C	2-3	3.340	961	1,308	1,656
Alfalfa hay.....	209	F	4-6	3.952	909	1,046	1,184
Alfalfa hay and mixed grain.....	209	F	1-3	3.832	1,048	1,282	1,516
Maize stover.....	210	D	1-3	4.147	879	1,144	1,405
Mixed hay.....	211	D	1-5	4.934	1,038	1,338	1,635
Mixed hay and hominy feed.....	211	D	3-2	5.028	855	1,178	1,498
Mixed hay.....	211	G	1-5	4.498	1,006	1,293	1,578
Mixed hay and maize meal.....	211	G	3-2	4.498	1,018	1,211	1,423
Alfalfa hay.....	212	H	1-5	4.236	862	1,124	1,310
Alfalfa meal.....	212	H	2-6	4.208	605	788	984
Alfalfa hay.....	216	J	5-7	4.589	840	1,117	1,382
Alfalfa hay and starch.....	216	J	1-4	4.458	1,023	1,200	1,381
Alfalfa hay and mixed grain.....	217	J	2-1	5.452	895	1,020	1,149
Do.....	217	J	3-4	5.506	1,176	1,370	1,565

TABLE IV.—Basal katabolism of cattle per square meter of body surface

	Lying 24 hours.	Standing 12 hours.	Standing 24 hours.
Mean.....Calories..	964	1,173	1,365
Probable error of mean.....do....	± 24.0	± 21.4	± 25.7
Probable error of single result.....do....	± 124.8	± 110.9	± 133.6
Standard deviation.....do....	185.1 ± 17.0	164.5 ± 15.1	198.0 ± 18.2
Coefficient of variability.....	0.1920	0.1462	0.1451

The data of Table III also show a positive correlation between the basal katabolism per square meter of body surface and the live weight, especially for the lying position, as appears from Table V. In other words, the basal katabolism tended to increase more rapidly than the body surface.

TABLE V.—Coefficients of correlation with live weight

	Basal katabolism per square meter.
Lying 24 hours.....	0.5375 ± 0.0923
Standing 12 hours.....	.3666 ± .1124
Standing 24 hours.....	.2405 ± .1223

MAINTENANCE REQUIREMENT OF CATTLE

In studying the results of feeding experiments it is often desirable to be able to estimate the maintenance requirements of animals. As already

pointed out, this is not fixed by the basal katabolism in the narrower sense, but includes also the energy expended in a variety of incidental activities, more or less variable in amount, and corresponding to what we have here called the 24-hour basal katabolism. Our results demonstrate anew the marked influence of standing upon the metabolism of cattle, the mean 24-hour basal katabolism lying, standing 12 hours and standing 24 hours being in the proportion of 100:121:141, the difference largely exceeding the probable errors. For expressing the actual maintenance re-

quirement we have customarily employed the results computed for 12 hours' standing, although this choice is purely arbitrary and any other ratio of standing to lying could be computed from the data of Table IV. If our previous practice be followed, the 24-hour basal katabolism—that is, the maintenance requirement—of an unfattened steer weighing 1,000 pounds (453.6 kgm.), equivalent to 403.7 kgm. empty weight, and standing half the time may be calculated by multiplying the basal katabolism per square

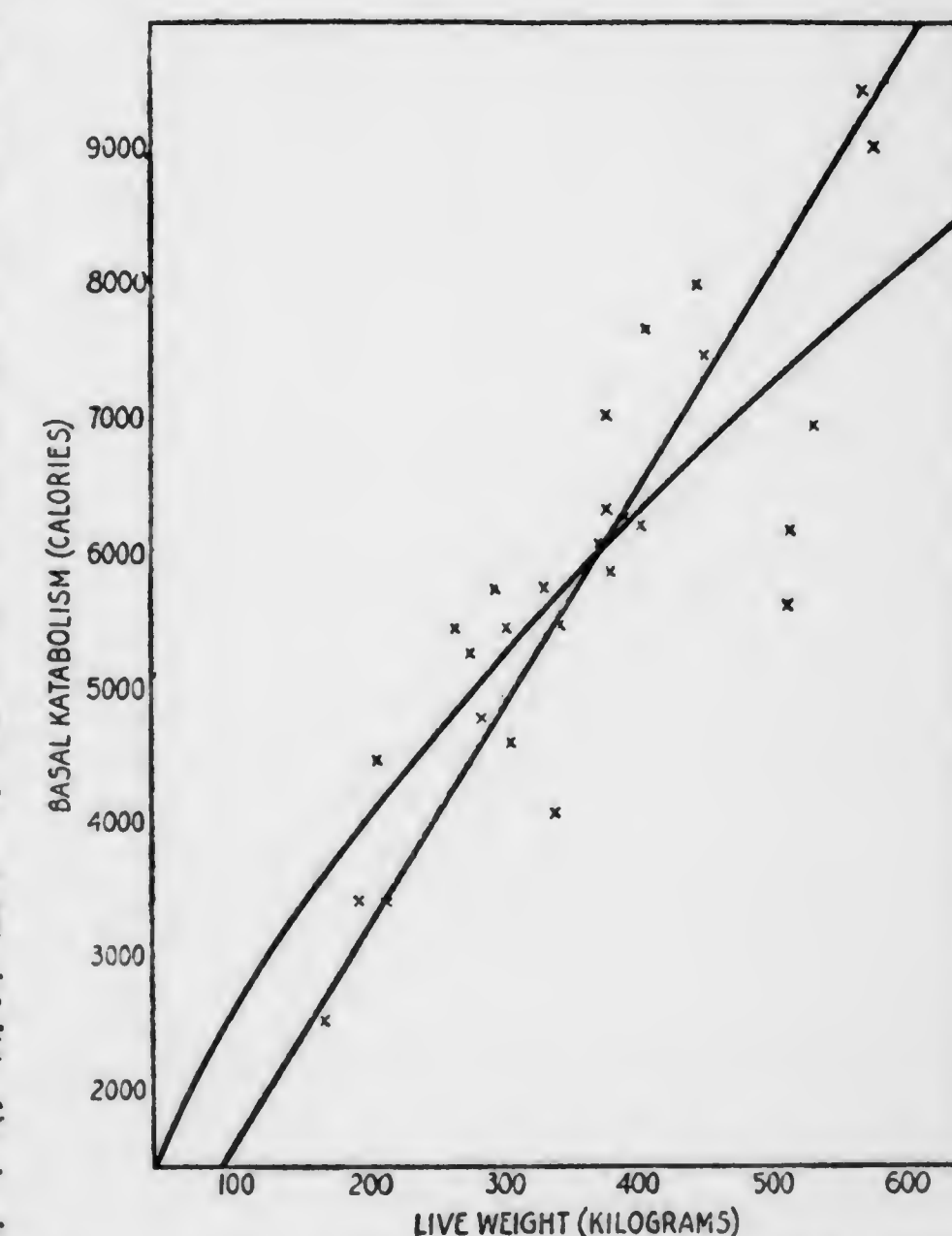


FIG. 3.—Graph of the basal katabolism of cattle per 24 hours' standing.

meter as recorded in Table IV by the body weight as computed by Moulton's formula (p. 47).

$$\text{Maintenance} = 1173 \pm 111 \times (0.1186 \times 403.7^{\frac{1}{2}}) = 5918 \pm 560 \text{ Calories.}$$

This result is substantially identical with that computed by the senior author (2, p. 289) from 23 of these same experiments in proportion to the two-thirds power of the live weight—viz, 5,906 Calories. No sufficient data seem to be available on which to base a similar computation for fattened animals.

RESULTS ON MAN

Numerous determinations of the basal katabolism of man have been reported, and it appears of some interest to compare their results with our data for cattle. We have not attempted to collate all the recorded

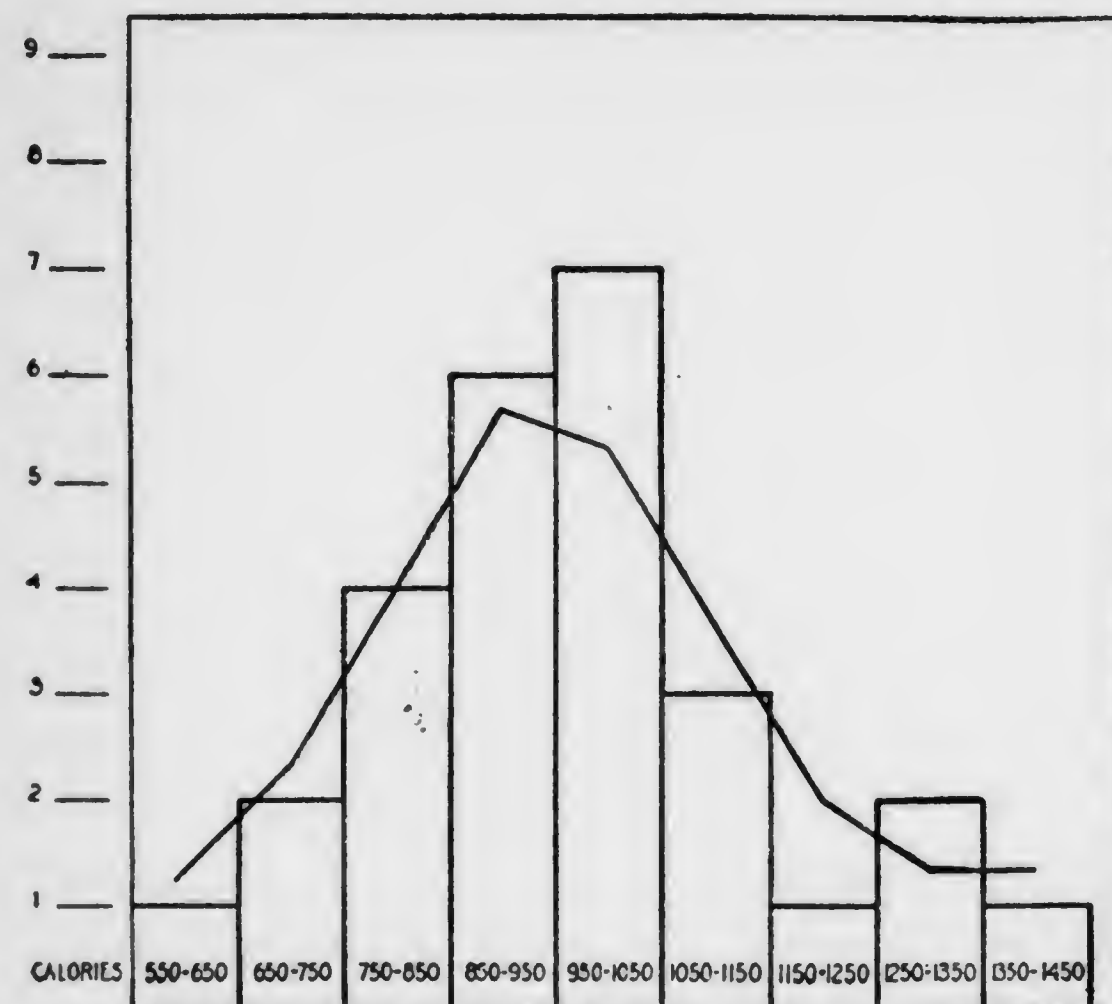


FIG. 4.—Graph of the frequency distribution of the basal katabolism of cattle per square meter of body surface lying 24 hours.

experiments on man, but have taken as representative those reported by Benedict, Emmes, Roth, and Smith (9) and by Means (14), including 98 observation on men and 75 on women. These determinations were made in short periods in the post-resorptive condition and in a state of as complete muscular rest as practicable. The majority of them were determinations of the pulmonary respiration made with

the Benedict respiration apparatus in periods of 10 to 20 minutes, although some were made with the bed calorimeter and extended over 2 to 3 hours. They therefore show substantially the basal katabolism in the narrower sense mentioned at the beginning of this article. The graphs accompanying Benedict's discussion (8) of the results reported in the paper first cited present much the same picture as do our results on cattle as shown in figures 1, 2, and 3, failing to indicate any close relation of basal katabolism to weight or body surface. This conclusion is confirmed by a statistical study of the data, including those reported by Means, which yields the results of Table VI. The correlation coefficients are distinctly lower than those obtained with cattle, but, like them, they fail to show any greater correlation with the body surface as computed by the Meeh formula than with the body weight.

TABLE VI.—Coefficients of correlation

Total basal katabolism.	With body weight.	With body surface.
98 men.....	0.7263 ± 0.0320	0.7747 ± 0.0272
75 women.....	.7759 ± .0310	.7447 ± .0347

For further statistical study the results for the heat production per square meter of surface have been grouped in classes covering a range of 25 Calories in the case of men and 31 Calories in the case of women. The frequency distribution of these classes is shown in figures 7 and 8.

The data corresponding to those for cattle recorded in Table IV are contained in Table VII. As would have been expected from

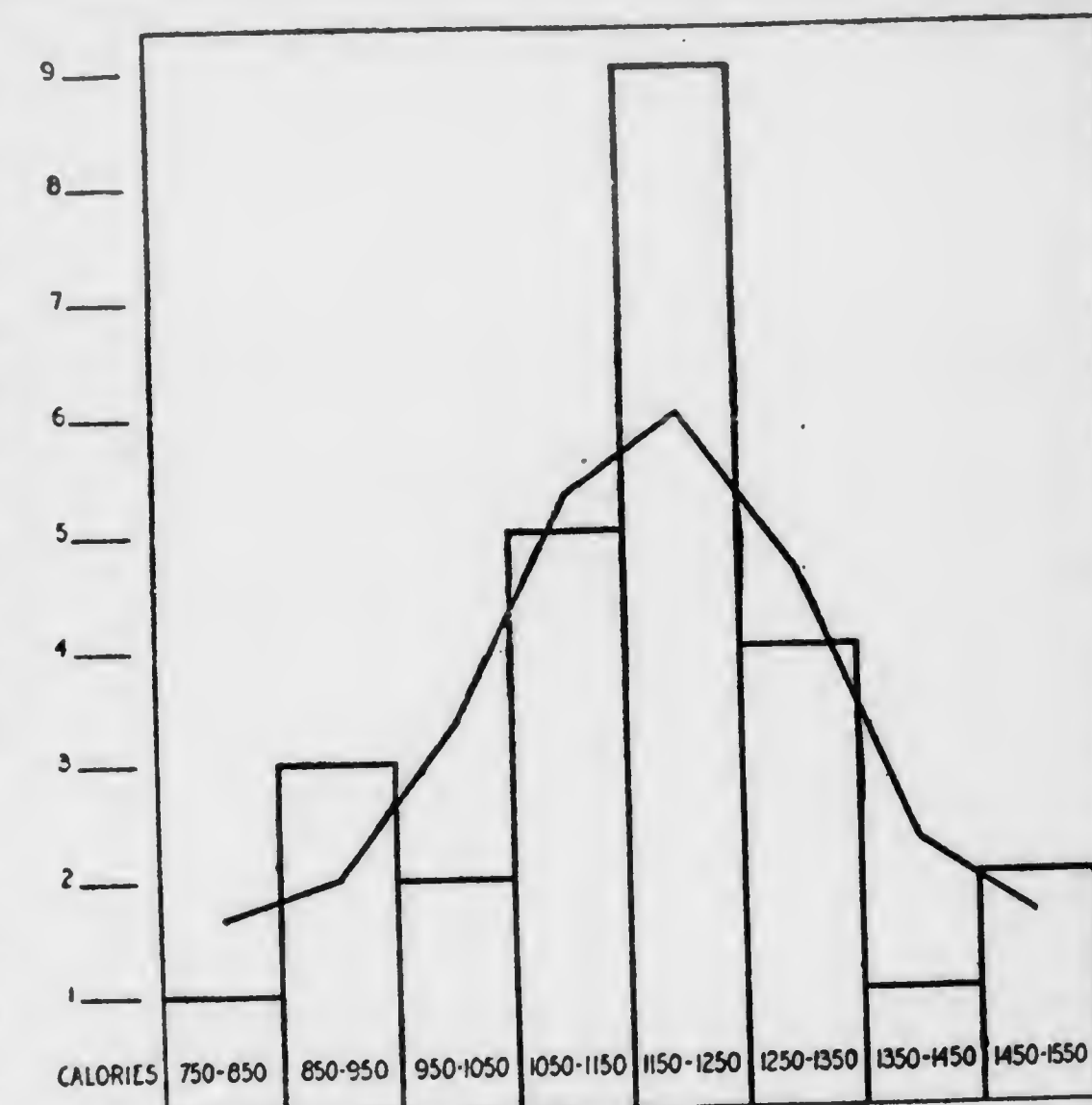


FIG. 5.—Graph of the frequency distribution of the basal katabolism of cattle per square meter of body surface lying 12 hours and standing 12 hours.

the more direct method available in experiments on man, the variability and the probable error are much lower than in the experiments on cattle.

TABLE VII.—Daily basal katabolism of men and women per square meter of body surface

	Men.	Women.
Mean.....Calories..	830	768
Probable error of mean.....do....	± 4.3	± 4.9
Probable error of single result.....do....	± 42.3	± 42.8
Standard deviation.....	62.7 ± 3.0	63.5 ± 3.1
Coefficient of variability.....	.0755	.0827

TABLE VIII.—Corrected daily basal katabolism of men and women per square meter of body surface

	Men.	Women.
Mean.....Calories..	935	886
Probable error of mean.....do....	± 4.8	± 5.8
Probable error of single result.....do....	± 47.5	± 49.4

In all these experiments the body surface was computed by the Meeh formula. D. and E. F. DuBois (10) have shown that the use of this formula gives too high results for the body surface of man as compared with direct measurement or with their "linear formula" and have also devised (11) a "height-weight chart" for the computation of body surface.

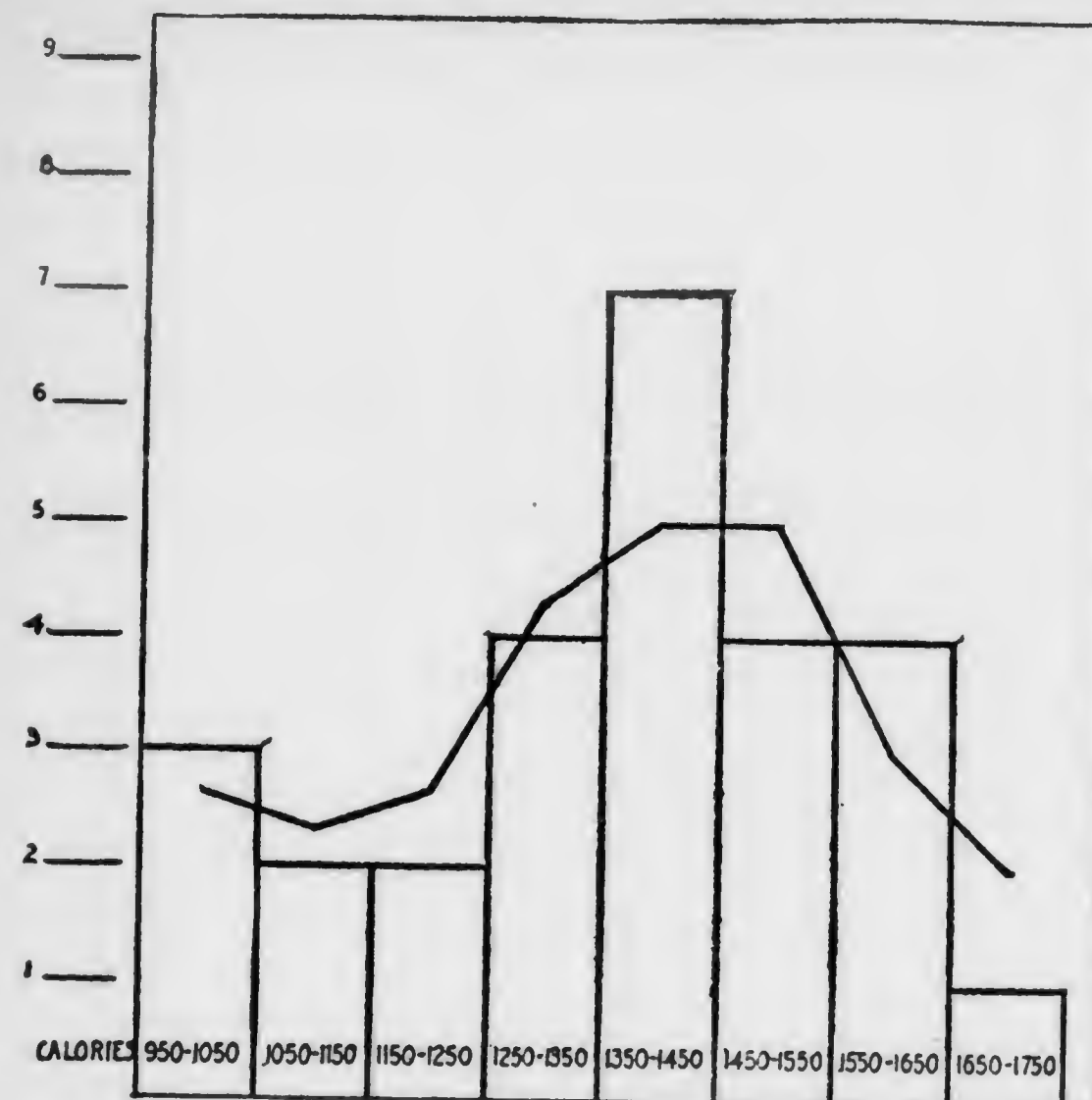


FIG. 6.—Graph of the frequency distribution of the basal katabolism of cattle per square meter of body surface standing 24 hours.

Recomputing Benedict's and Mean's results by this latter method, Gephart and E. F. DuBois (13) estimate the mean basal katabolism to be 38.97 Calories per square meter per hour for 88 men and 36.9 Calories per square meter per hour for 68 women. Correcting the figures of Table VII in this proportion the basal katabolism per 24 hours and the probable errors are as shown in Table VIII. Considering that these means represent a condition of minimum muscular activity they show a rather striking approximation to that for cattle in the lying position but otherwise free to move.

RESULTS ON THE HOG AND THE HORSE

Determinations of the basal katabolism of swine have been reported by Meissl, Strohmer, and Lorenz (16) and by Tangl (18), while Fingerling, Köhler, and Reinhardt (12) have computed it from a comparison of the gains made at two different ages and weights by growing pigs. Their results per square meter of body surface (estimated by Meeh's formula, using for k the value 9.02 found by Hecker for the horse) are recorded in Table IX. In both Tangl's and Fingerling's experiments the animals spent most of the time in the lying position. Meissl makes no statement on this point.

TABLE IX.—Basal katabolism of swine per 24 hours per square meter of body surface

Investigators.	State of animal.	Basal katabolism.
		Calories
Meissl et al.	Mature animals.	1, 117
		1, 084
Tangl.	do.	1, 063
		1, 066
Do.	Growing animals.	1, 139
		1, 068
Fingerling et al.	do.	1, 129
		960
Mean.		1, 078

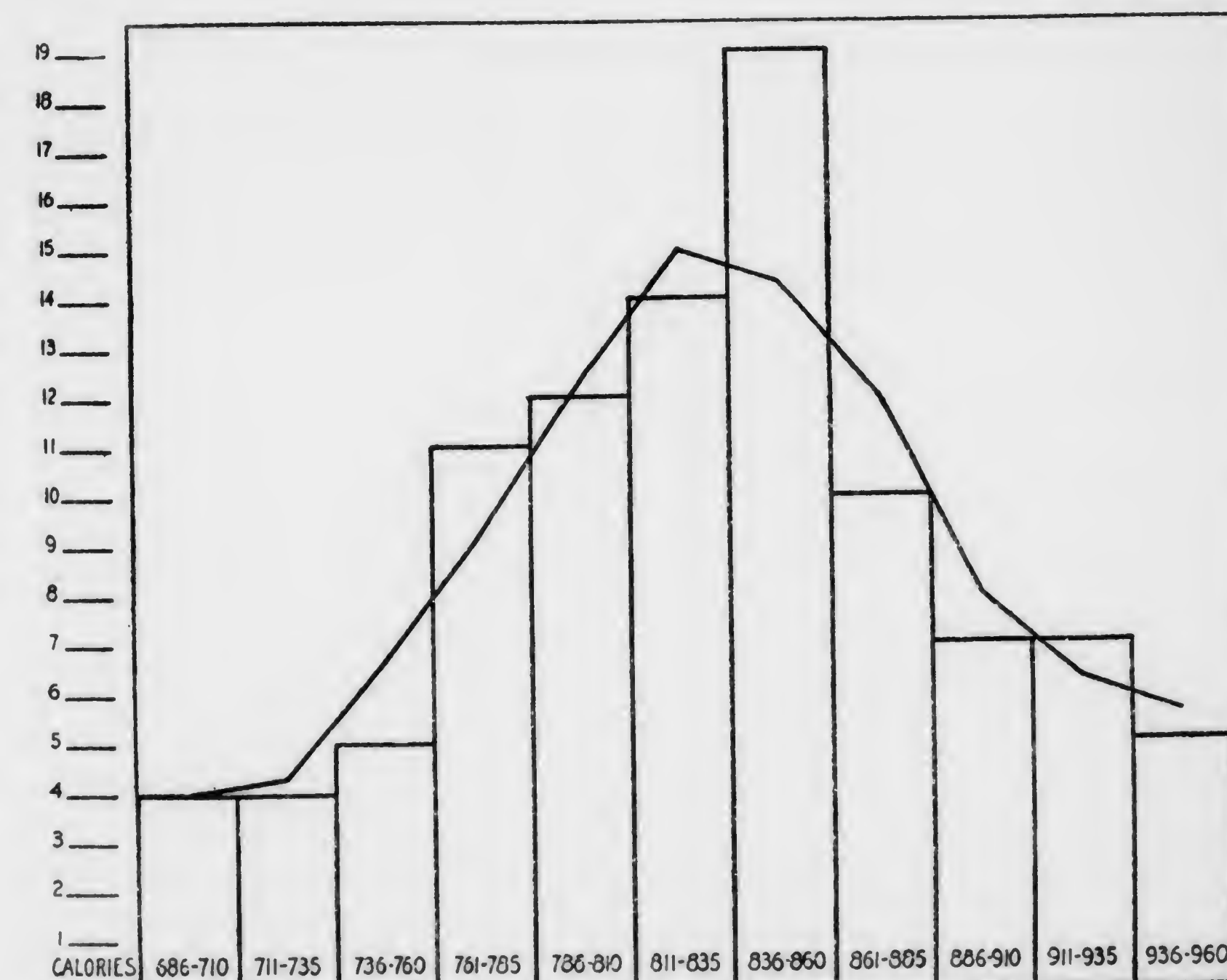


FIG. 7.—Graph of the frequency distribution of the basal katabolism of men per square meter of body surface. Complete muscular rest.

Zuntz and Hagemann (22, p. 284) have computed the basal katabolism of the horse from the results of numerous determinations of the respiratory exchange while standing quietly. Their method of computation is in principle the same as that which we have used for cattle, although the experimental methods are entirely different. Their results were as shown in Table X.

TABLE X.—*Computed fasting katabolism of the horse per square meter of body surface per 24 hours*

Period.	Season.	Calories.
a.....	Winter.....	807
b.....	Summer.....	767
e.....	Winter.....	879
f.....	Summer.....	936
i.....	Winter.....	802
n.....	Summer.....	1,085
c.....	do.....	976
No. 118c.....	Winter.....	1,333
Mean.....		948

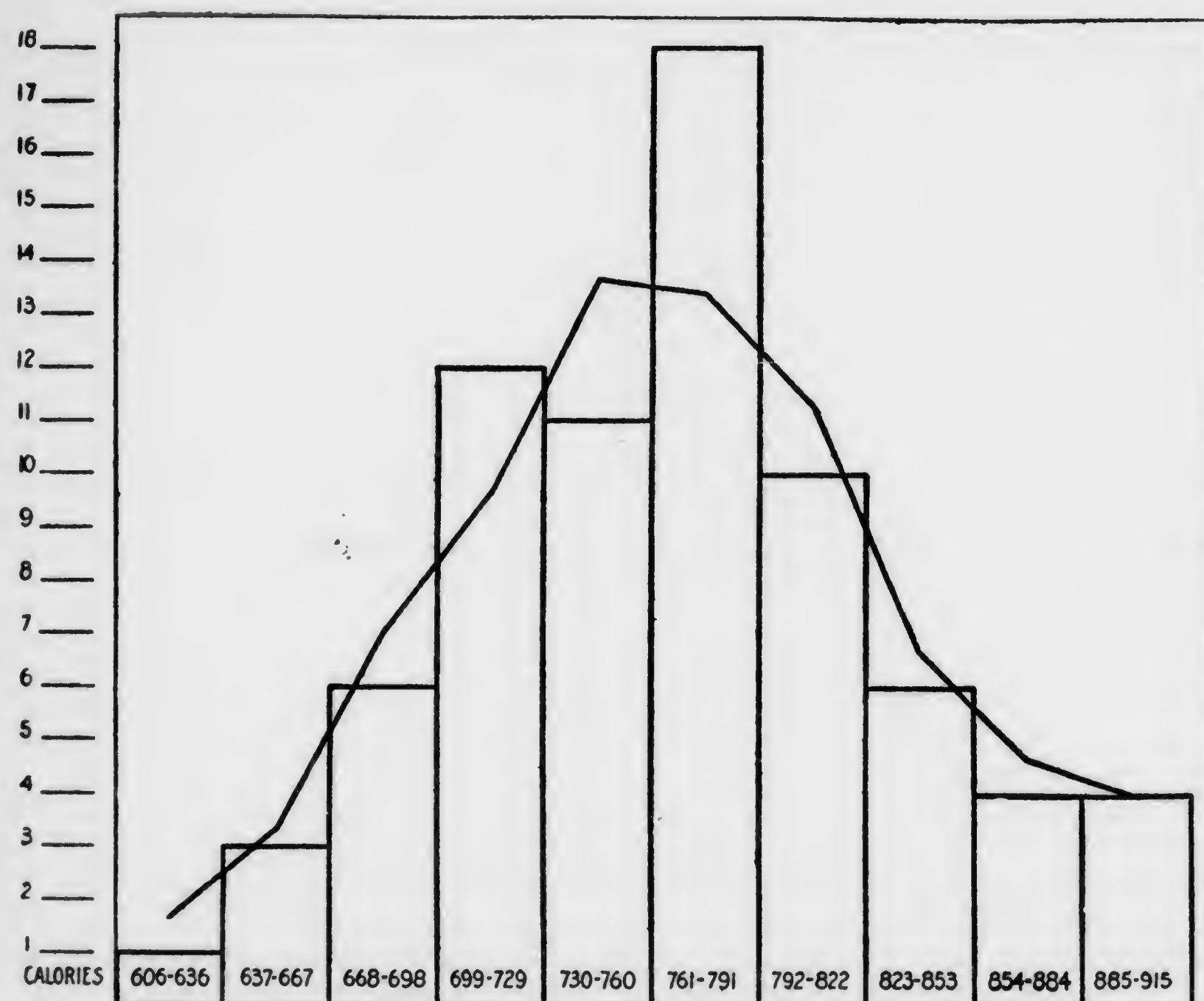


FIG. 8.—Graph of the frequency distribution of the basal katabolism of women per square meter of body surface. Complete muscular rest.

Zuntz and Hagemann regard the lowest of these values, obtained on an exclusive hay ration, as representing the basal katabolism of the horse and regard the higher results as due to a stimulation of the metabolism in periods of light feeding or of low temperature for the sake of heat production—i. e., to a “chemical” regulation of the body temperature.

COMPARISON OF SPECIES

Summarizing the foregoing means from the different species affords the comparisons of Table XI. Considering the nature of the results, they show a rather striking degree of uniformity and tend to confirm the conclusions of Voit (20) that the basal katabolism of different species of animals is substantially proportional to their body surface. It may be surmised that the exceptional result with the hog may be due to the imperfect data available for computing the body surface of this species.

TABLE XI.—*Mean daily basal katabolism per square meter of body surface*

Species.	Basal katabolism.
	Calories.
Men (complete muscular rest).....	935 ± 5
Women (complete muscular rest).....	886 ± 6
Cattle (lying).....	964 ± 24
Hogs (lying).....	1,078 ± ?
Horse (standing quietly).....	948 ± ?

SUMMARY

- (1) The results of 27 determinations of the daily basal katabolism of unfattened cattle of different weights and ages are reported.
- (2) The basal katabolism, whether computed lying or standing or for an equal proportion of each, was equally well correlated with the estimated body surface and with the live weight.
- (3) The basal katabolism per unit of body surface showed considerable variability and a positive correlation with the live weight.
- (4) The mean basal katabolism lying, standing 12 hours, and standing 24 hours was in the proportion of 100:121:141.
- (5) The mean daily katabolism of a 1,000-pound, unfattened steer standing 12 hours out of the 24 is computed to be $5,918 \pm 60$ Calories.
- (6) Experiments upon man have given results regarding the correlation between basal katabolism and weight or body surface which substantially correspond with those upon cattle.
- (7) The mean daily basal katabolism per square meter of body surface appears not to differ greatly in man, cattle, swine, and horses under comparable conditions.

LITERATURE CITED

- (1) ARMSBY, H. P.
1912. THE MAINTENANCE RATIONS OF FARM ANIMALS. U. S. Dept. Agr. Bur. Anim. Indus. Bul. 143, 110 p.
- (2) ———
1917. THE NUTRITION OF FARM ANIMALS. 743 p., 45 fig. New York.

- (3) ARMSBY, H. P., and FRIES, J. A.
1911. THE INFLUENCE OF TYPE AND OF AGE UPON THE UTILIZATION OF FEED BY CATTLE. U. S. Dept. Agr. Bur. Anim. Indus. Bul. 128, 245 p., 17 fig., 3 pl.
- (4) ———
1915. NET ENERGY VALUES OF FEEDING STUFFS FOR CATTLE. *In Jour. Agr. Research*, v. 3, no. 6, p. 435-491, 2 fig. Literature cited, p. 489-491.
- (5) ———
1917. ENERGY VALUES OF HOMINY FEED AND MAIZE MEAL FOR CATTLE. *In Jour. Agr. Research*, v. 10, no. 12, p. 599-613. Literature cited, p. 613.
- (6) ———
1917. INFLUENCE OF THE DEGREE OF FATNESS OF CATTLE UPON THEIR UTILIZATION OF FEED. *In Jour. Agr. Research*, v. 11, no. 10, p. 451-472, pl. 41. Literature cited, p. 464.
- (7) ——— and BRAMAN, W. W.
1916. ENERGY VALUES OF RED-CLOVER HAY AND MAIZE MEAL. *In Jour. Agr. Research*, v. 7, no. 9, p. 379-387.
- (8) BENEDICT, F. G.
1915. FACTORS AFFECTING BASAL METABOLISM. *In Jour. Biol. Chem.*, v. 20, no. 3, p. 263-299, 6 fig.
- (9) ——— and others.
1914. THE BASAL, GASEOUS METABOLISM OF NORMAL MEN AND WOMEN. *In Jour. Biol. Chem.*, v. 18, no. 2, p. 139-155.
- (10) DuBOIS, D., and DuBOIS, E. F.
1915. THE MEASUREMENT OF THE SURFACE AREA OF MAN. *In Arch. Int. Med.*, v. 15, no. 5, p. 868-881, 2 fig.
- (11) ———
1916. A FORMULA TO ESTIMATE THE APPROXIMATE SURFACE AREA IF HEIGHT AND WEIGHT BE KNOWN. *In Arch. Int. Med.*, v. 17, no. 6, p. 863-871.
- (12) FINGERLING, G., KÖHLER, A., and REINHARDT, Fr.
1914. UNTERSUCHUNGEN ÜBER DEN STOFF- UND ENERGIEUMSATZ WACHSENDER SCHWEINE. *In Landw. Vers. Stat.*, v. 84, Heft 3/4, p. 149-230.
- (13) GEPHART, F. C., and DuBOIS, E. F.
1916. THE BASAL METABOLISM OF NORMAL ADULTS WITH SPECIAL REFERENCE TO SURFACE AREA. *In Arch. Int. Med.*, v. 17, no. 6, p. 902-914.
- (14) MEANS, J. H.
1915. BASAL METABOLISM AND BODY SURFACE. *In Jour. Biol. Chem.*, v. 21, no. 2, p. 263-268, 2 fig.
- (15) MEEH, K.
1879. OBERFLÄCHENMESSUNGEN DES MENSCHLICHEN KÖRPERS. *In Ztschr. Biol.*, Bd. 15, p. 425-458.
- (16) MEISSL, E., STROHMER, F., and LORENZ, H. von.
1886. UNTERSUCHUNGEN ÜBER DEN STOFFWECHSEL DES SCHWEINES. *In Ztschr. Biol.*, Bd. 22 (n. F., Bd. 4), p. 63-160.
- (17) MOULTON, C. R.
1916. UNITS OF REFERENCE FOR BASAL METABOLISM AND THEIR INTERRELATIONS. *In Jour. Biol. Chem.*, v. 24, no. 3, p. 299-320, 21 fig.
- (18) TANGL, Franz.
1912. DIE MINIMALE ERHALTUNGSARBEIT DES SCHWEINES. (STOFF- UND ENERGIEUMSATZ IN HUNGER.) *In Biochem. Ztschr.*, Bd. 44, Heft 3/4, p. 252-278.

- (19) TROWBRIDGE, P. F., MOULTON, C. R., and HAIGH, L. D.
1915. THE MAINTENANCE REQUIREMENT OF CATTLE AS INFLUENCED BY CONDITION, PLANE OF NUTRITION, AGE, SEASON, TIME ON MAINTENANCE, TYPE, AND SIZE OF ANIMAL. *Mo. Agr. Exp. Sta. Research Bul.* 18, 62 p., 1 fig., 17 pl.
- (20) VOIT, Erwin.
1901. ÜBER DIE GRÖSSE DES ENERGIEBEDARFES DER TIERE IM HUNGER-ZUSTANDE. *In Ztschr. Biol.*, Bd. 41 (n. F., Bd. 23), p. 113-154.
- (21) WOOD, T. B., and YULE, G. U.
1914. STUDIES OF BRITISH FEEDING TRIALS AND THE STARCH EQUIVALENT THEORY. *In Jour. Agr. Sci.*, v. 6, pt. 2, p. 233-251, 7 fig.
- (22) ZUNTZ, N., and HAGEMANN, Oscar.
1898. UNTERSUCHUNGEN ÜBER DEN STOFFWECHSEL DES PFERDES BEI RUHE UND ARBEIT. *In Landw. Jahrb.*, Bd. 27, Ergänzungsbd. 3, 438 p., 7 pl.

NET ENERGY VALUES OF ALFALFA HAY AND OF STARCH

By HENRY PRENTISS ARMSBY, *Director*, and J. AUGUST FRIES, *Assistant Director*,
Institute of Animal Nutrition of the Pennsylvania State College

COOPERATIVE INVESTIGATIONS BETWEEN THE BUREAU OF ANIMAL INDUSTRY OF
THE UNITED STATES DEPARTMENT OF AGRICULTURE AND THE INSTITUTE OF
ANIMAL NUTRITION OF THE PENNSYLVANIA STATE COLLEGE

INTRODUCTION

The experiments here reported were undertaken primarily to determine the net energy value of starch as a representative of the carbohydrates. Alfalfa hay was used as the necessary roughage chiefly in order to secure a mixed ration not too low relatively in protein, but in part also for the sake of comparison with the results of several earlier determinations on the same feeding stuff.

OUTLINE OF EXPERIMENT

The subject of the experiment was a pure-bred Shorthorn steer, designated as Steer J, bred by The Pennsylvania State College. He was a year and 10 months old at the beginning of the experiment and had been chiefly grass fed up to that time. He was the same animal used in the subsequent year for the experiment on the influence of the degree of fatness of cattle upon their utilization of feed already reported.¹

The general plan of the experiment was the same which has been employed in our more recent determinations of the net energy values of concentrates. It consisted, first, in determining with the aid of the respiration calorimeter, the net energy value of the roughage by a comparison of two or more periods in which different amounts of it were fed and second, in making similar determinations upon a mixture of hay and starch in the proportion of 2.5 to 1. By a difference calculation, precisely similar in principle to that commonly used in estimating the digestibility of a concentrate, the net energy of the starch could then be computed.² As a matter of fact, the trials were not actually made in this order, those on the mixed ration preceding those on the hay.

It may be noted that this method differs from that employed by Kellner, who has also reported a number of determinations of the net energy value of starch.³ In his experiments the starch was added to a basal ration of hay and grain, the balance of carbon and nitrogen on each

¹ ARMSBY, H. P., and FRIES, J. A. INFLUENCE OF THE DEGREE OF FATNESS OF CATTLE UPON THEIR UTILIZATION OF FEED. *In Jour. Agr. Research*, v. 11, no. 10, p. 451-472, Pl. 41. Literature cited, p. 464. 1917.

² ——— NET ENERGY VALUES OF FEEDING STUFFS FOR CATTLE. *In Jour. Agr. Research*, v. 3, no. 6, p. 469-470. 1915.

³ KELLNER, O., and KÖHLER, A. UNTERSUCHUNGEN ÜBER DEN STOFF- UND ENERGIE-UMSATZ DES ERWACHSENEN RINDES BEI ERHALTUNGS- UND PRODUKTIONSFUTTER. *In Landw. Vers. Sta., Bd. 53*, 474 P. 1900.

ration being determined with a respiration apparatus and the heat production computed. A difference calculation, after making certain corrections, shows the net energy of the added starch.

PERIOD AND RATIONS

Each feeding period covered three weeks, of which the first 11 days constituted the preliminary period while during the last 10 the feces and urine were collected quantitatively. A 48-hour determination of the respiratory products and of the heat production was made on the eighteenth and nineteenth days of each period. The dates of the several periods, the rations fed and the average live weight of the animal in each period are shown in Table I.

TABLE I.—Periods, rations, and average live weights

Period.	Preliminary period.	Digestion period.	Daily rations.		Live weights of steer.
			Hay.	Starch.	
	1912-13.	1913.	Kgm.	Kgm.	Kgm.
Period 1.....	Dec. 22-Jan. 1	Jan. 2-Jan. 11	7.50	3.00	388.7
Period 2.....	Jan. 12-Jan. 22	Jan. 23-Feb. 1	3.00	1.20	366.5
Period 3.....	Feb. 2-Feb. 12	Feb. 13-Feb. 22	4.25	1.70	387.0
Period 4.....	Feb. 23-Mar. 5	Mar. 6-Mar. 15	2.00	.80	356.2
Period 5.....	Mar. 16-Mar. 26	Mar. 27-Apr. 5	9.00	.....	403.8
Period 6.....	Apr. 6-Apr. 16	Apr. 17-Apr. 26	7.00	.....	403.2
Period 7.....	Apr. 27-May 7	May 8-May 17	4.00	.....	377.0

COMPOSITION OF FEEDING STUFFS

The alfalfa hay was from a car of baled hay purchased the previous year in Kansas City, Mo., and stated to have been grown in Idaho. The starch was commercial cornstarch

TABLE II.—Composition and energy content of dry matter of feeding stuffs

	Alfalfa hay.					Starch, Periods 1-4.
	Period 1.	Periods 2 and 3.	Periods 4 and 5.	Periods 6 and 7.	Average.	
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Ash.....	9.74	8.83	9.27	9.43	9.26	0.24
Protein.....	11.34	10.96	11.36	11.51	11.29	.35
Nonprotein.....	3.27	3.21	3.03	3.12	3.14	.....
Crude fiber.....	30.69	31.86	29.46	29.96	30.47	.13
Nitrogen-free extract....	43.22	43.38	45.14	44.21	44.10	99.28
Ether extract.....	1.84	1.76	1.74	1.77	1.77	.....
	100.00	100.00	100.00	100.00	100.00	100.00
Total nitrogen.....	2.51	2.44	2.46	2.51	2.48	.06
Protein nitrogen.....	1.82	1.75	1.82	1.84	1.81	.....
Carbon.....	45.00	44.94	44.98	44.74	44.92	43.64
Energy, calories per kgm.	4,335.34	4,389.90	4,332.82	4,334.67	4,348.18	4,104.85

Four samples of the finely cut alfalfa hay and four of the starch were taken as the rations were being weighed out. The hay samples were analyzed separately, while the starch samples were united to form a single composite. The analytical results and the periods covered by each sample are shown in Table II.

DIGESTIBILITY

The digestibility of the total ration was determined in the usual manner. The results are recorded in full in Table I of the Appendix and are summarized in Table III. The weighted means are computed from the totals of each ingredient eaten and excreted respectively in all the periods averaged. The digestibility of the starch is computed on the assumption that the hay fed with it had the digestibility shown by the mean of periods 5, 6 and 7. Large negative coefficients for protein and crude fiber result from this computation. The results for the other ingredients are as shown in the table, the periods being, for convenience of reference, grouped by the nature of the ration and arranged in each group in the order of magnitude of the rations.

TABLE III.—Summary of percentage digestibility

Feed and period.	Dry matter.	Ash.	Organic matter.	Protein.	Non-protein.	Crude fiber.	Nitrogen-free extract.	Ether extract.	Total nitrogen.	Carbon.	Energy.
ALFALFA HAY											
Period 5, 7,893 gm.....	58.22	41.04	59.98	66.86	87.15	41.24	70.35	15.96	72.57	56.94	56.73
Period 6, 6,128 gm.....	59.49	40.92	61.42	69.21	89.52	44.07	71.27	8.96	72.64	57.59	57.55
Period 7, 3,502 gm.....	60.47	42.31	62.36	69.54	90.65	44.71	72.04	22.49	73.55	58.64	58.65
Weighted means..	59.11	41.25	60.96	68.23	88.66	42.94	71.00	14.81	72.79	57.50	57.40
ALFALFA HAY AND STARCH											
Period 1, 8,821 gm.....	68.86	44.54	70.68	60.04	87.64	39.26	83.11	23.57	62.99	67.64	67.30
Period 3, 5,299 gm.....	67.73	48.86	69.00	56.13	88.86	41.85	81.20	21.18	62.80	66.04	65.98
Period 2, 3,750 gm.....	70.12	47.42	71.65	61.92	88.57	44.96	83.43	17.81	66.31	68.74	68.57
Period 4, 2,480 gm.....	70.61	48.63	72.17	63.13	88.70	42.80	84.09	11.15	64.68	68.95	68.48
Weighted means..	69.01	46.62	70.61	59.77	88.25	41.49	82.78	20.45	63.71	67.58	67.34
Weighted means, omitting period 3.....	69.46	45.88	71.17	61.01	88.04	41.35	83.36	20.20	64.07	68.13	67.82
STARCH											
(Computed using mean digestibility of hay)											
Period 1.....	92.62	.....	92.11	.....	.....	.....	96.46	.....	93.10	92.78	.....
Period 3.....	88.55	.....	86.76	.....	.....	.....	91.96	.....	87.28	88.14	.....
Period 2.....	96.48	.....	95.03	.....	.....	.....	96.45	.....	96.45	97.16	.....
Period 4.....	98.39	.....	96.80	.....	.....	.....	98.46	.....	97.48	96.75	.....
Weighted means..	92.98	.....	91.83	.....	.....	.....	95.53	.....	92.74	92.87	.....
Weighted means, omitting period 3.....	94.55	.....	93.61	.....	.....	.....	96.80	.....	94.66	94.53	.....

The negative coefficients obtained for the protein and crude fiber of the starch by the foregoing method of computation are, of course, simply an expression of the well-known fact that the addition of starch to a ration

usually results in depressing the digestibility of these ingredients. If it be assumed that the starch was completely digestible—that is, if all the effects just mentioned be assigned to the hay—the digestibility of the latter as compared with that observed in the periods when the hay was fed alone was as shown in Table IV.

TABLE IV.—Influence of starch on digestibility of hay

	Dry matter.	Ash.	Organic matter.	Protein.	Non-protein.	Crude fiber.	Nitrogen-free extract.	Ether extract.	Total nitrogen.	Carbon.	Energy.
Computed digestibility, assuming 100 per cent for starch:											
Period 1.....	56.08	43.96	57.38	59.54	87.64	39.15	67.80	23.57	62.64	54.75	54.59
Period 3.....	50.83	48.28	54.96	55.55	88.86	41.76	63.37	21.18	62.43	52.38	52.82
Period 2.....	57.64	46.81	58.69	61.42	88.57	44.77	67.60	17.81	66.01	56.06	56.30
Period 4.....	58.44	48.07	59.50	62.67	88.70	42.70	69.60	11.15	64.35	56.48	56.12
Weighted means.....	56.21	46.03	57.25	59.25	88.25	41.39	66.86	20.45	63.40	54.54	54.62
Weighted means, omitting period 3.....	56.86	45.29	58.06	60.51	88.04	41.25	68.05	20.20	63.73	55.36	55.27
Observed digestibility.....	59.11	47.25	60.96	68.23	88.66	42.94	71.00	14.81	72.79	57.50	57.40
Difference.....	-2.25	+4.04	-2.90	-7.72	-0.62	-1.67	-2.95	+5.39	-9.06	-2.14	-2.13

In some respects a more rational method of expressing this depression in digestibility is in terms of the actual amounts instead of the percentages of the various ingredients. Table V shows the number of grams by which the several nutrients actually digested from the mixed ration of periods 1 to 4 differ from what would be expected on the same assumption as in Table IV.

TABLE V.—Depression of digestibility by starch

Period No.	Protein.	Non-protein.	Crude fiber.	Total nitrogen.
	Gm.	Gm.	Gm.	Gm.
1.....	61.7	2.1	68.6	16.0
3.....	52.1	— .2	14.1	9.5
2.....	19.7	.1	-16.3	4.4
4.....	11.1	.0	1.2	3.6

INFLUENCE OF QUANTITY OF FEED ON DIGESTIBILITY

The figures of Table III show a distinct influence of the quantity of feed upon the percentage digestibility, as has been the case in most previous experiments.¹ The digestibility increases as the amount consumed is decreased, although the differences are relatively small. To this rule period 3 constitutes a distinct exception. As will appear, the results of

¹ ARMSBY, H. P. THE NUTRITION OF FARM ANIMALS. p. 613-618. New York, 1917.
 — and FRIES, J. A. ENERGY VALUES OF HOMINY FEED AND MAIZE MEAL FOR CATTLE. In Jour. Agr. Research, v. 10, no. 12, p. 605. 1917.
 — INFLUENCE OF THE DEGREE OF FATNESS OF CATTLE UPON THEIR UTILIZATION OF FEED. In Jour. Agr. Research, v. 11, no. 10, p. 453. 1917.
 — and BRAMAN, W. W. ENERGY VALUES OF RED-CLOVER HAY AND MAIZE MEAL. In Jour. Agr. Research, v. 7, no. 9, p. 381. 1916.

this period appear somewhat exceptional in other respects also, and the mean digestibility, excluding period 3, is therefore included in the table.

URINARY EXCRETION

From the results for the urinary excretion contained in Table 2 of the Appendix the following averages are derived. Table VI shows both the energy of the urine as actually determined and also with a correction of 7.45 Calories per gram for the gain or loss of nitrogen by the body.

TABLE VI.—Average daily excretion in urine

Feed and period.	Nitrogen.	Carbon.	Energy.		Ratio of nitrogen to carbon.	Observed energy.	
			Observed.	Corrected to nitrogen equilibrium.		Per gram of nitrogen.	Per gram of carbon.
ALFALFA HAY.	Gm.	Gm.	Cal.	Cal.		Cal.	Cal.
Period 5.....	129.7	196.4	1,916.1	1,992.1	1:1.51	14.77	9.76
Period 6.....	100.9	151.5	1,489.5	1,560.3	1:1.50	14.76	9.83
Period 7.....	70.6	107.7	997.5	943.9	1:1.53	14.13	9.26
ALFALFA HAY AND STARCH							
Period 1.....	66.8	140.5	1,229.0	1,467.4	1:2.10	18.40	8.75
Period 3.....	49.7	100.5	902.6	955.5	1:2.02	18.16	8.98
Period 2.....	43.1	78.3	733.3	725.1	1:1.82	17.01	9.37
Period 4.....	35.1	58.8	564.9	505.3	1:1.68	16.09	9.61

GASEOUS EXCRETION

The excretion of water vapor, carbon dioxide, and methane for each day is recorded in Table 4 of the Appendix. The average results for each period were as follows:

TABLE VII.—Average daily gaseous excretion

Feed and period.	Water.	Carbon dioxide.	In combustible gases.		Methane computed from carbon.	Ratio of hydrogen to carbon.
			Hydrogen.	Carbon.		
ALFALFA HAY.	Gm.	Gm.	Gm.	Gm.	Gm.	
Period 5.....	6,995.3	5,505.0	42.4	129.6	173.2	3.057
Period 6.....	5,458.7	4,568.6	33.5	99.3	132.7	2.970
Period 7.....	3,460.1	3,252.5	26.1	59.3	79.2	2.267
ALFALFA HAY AND STARCH.						
Period 1.....	10,028.1	7,045.5	54.9	168.5	225.1	3.069
Period 3.....	5,252.6	4,724.9	37.7	116.7	155.9	3.092
Period 2.....	4,384.3	3,909.5	27.1	83.8	112.0	3.092
Period 4.....	3,168.8	3,133.7	19.8	62.4	83.3	3.145

GAINS BY BODY

From the data of the Appendix the gains of protein, fat, and water by the animal can be computed in the usual way with the results there recorded in Table 6. In this computation the amount of water produced by the oxidation of organic hydrogen has been disregarded. The results are used only as a correction in the manner described on page 277, and it may be shown that a disregard of the organic hydrogen introduces no material error. Table VIII contains a summary of the gains of protein and fat by periods.

TABLE VIII.—Average daily gains of protein and fat

Feed and period.	Protein.	Fat.
ALFALFA HAY.		
	Gm.	Gm.
Period 5.....	61.2	205.3
Period 6.....	57.0	60.9
Period 7.....	-43.2	-154.0
ALFALFA HAY AND STARCH.		
Period 1.....	192.0	422.9
Period 3.....	42.6	34.1
Period 2.....	-6.6	-106.2
Period 4.....	-48.0	-252.6

METHANE FERMENTATION

The extent of the methane fermentation per kilogram of dry matter of the feed and per 100 gm. of digested carbohydrates is shown in Table IX. In the hay the carbohydrates are the sum of the digested crude fiber and nitrogen-free extract, while in the case of starch the comparison is made with the digested nitrogen-free extract. The minute amount of crude fiber contained in the starch, as already noted, showed an apparent negative digestibility.

The extent to which the carbohydrates of the hay were subject to the methane fermentation was substantially the same as the average of 17 previous determinations on alfalfa¹—viz, 4.9 gm. of CH₄ per 100 gm. of carbohydrates as compared with an average of 4.8. With the mixed ration of hay and starch the fermentation showed a distinct increase as the amount of feed was diminished. When, as in the latter part of the table, this increase is computed upon the starch alone, assuming average figures for the hay, it becomes, of course, relatively more marked and considerably exceeds Kellner's average of 3.07.² The relative extent of the fermentation was apparently abnormally great in period 3 which, as already noted, also gave apparently exceptional results as regards digestibility. The means, omitting period 3, have therefore been included in the table.

¹ ARMSBY, H. P., and FRIES, J. A. NET ENERGY VALUES OF FEEDING STUFFS FOR CATTLE. In Jour. Agr. Research, v. 3, no. 6, p. 450. 1915.

² KELLNER, O., and KÖHLER, A. UNTERSUCHUNGEN ÜBER DEN STOFF- UND ENERGIE-UMSATZ DES ERWACHSENEN RINDES BEI ERHALTUNGS- UND PRODUKTIONSFUTTER. In Landw. Vers. Stat., Bd. 52, p. 423, 1900.

TABLE IX.—Methane production

Feed and period.	Dry matter eaten.	Methane.		
		Total.	Per kilo-gram of dry matter.	Per 100 grams of digested carbohydrates.
ALFALFA HAY.				
	Gm.	Gm.	Gm.	Gm.
Period 5	7,893. 0	173. 19	21. 94	5. 0
Period 6	6,127. 8	132. 74	21. 66	4. 8
Period 7	3,501. 6	79. 19	22. 61	5. 0
Totals and means	17,522. 4	385. 12	21. 98	4. 9
ALFALFA HAY AND STARCH.				
Period 1	8,821. 0	225. 14	25. 52	4. 4
Period 3	5,298. 8	155. 93	29. 42	5. 1
Period 2	3,750. 4	112. 00	29. 86	5. 0
Period 4	2,480. 0	83. 34	33. 60	5. 6
Totals and means	20,350. 2	576. 41	28. 32	4. 8
Totals and means, omitting period 3	15,051. 4	420. 48	27. 94	4. 7
STARCH, COMPUTED, WITH MEAN FOR HAY.				
Period 1, total	8,821. 0	225. 14		
Period 1, hay	6,254. 7	137. 48		
Period 1, starch	2,566. 3	87. 66	34. 16	3. 6
Period 3, total	5,298. 8	155. 93		
Period 3, hay	3,747. 7	82. 37		
Period 3, starch	1,551. 1	73. 56	47. 42	5. 2
Period 2, total	3,750. 4	112. 00		
Period 2, hay	2,645. 4	58. 15		
Period 2, starch	1,105. 0	53. 85	48. 73	5. 1
Period 4, total	2,480. 0	83. 34		
Period 4, hay	1,754. 0	38. 55		
Period 4, starch	726. 0	44. 79	61. 70	6. 3
Totals and means	5,948. 4	259. 86	43. 69	4. 6
Totals and means, omitting period 3	4,397. 3	186. 30	42. 37	4. 4

METABOLIZABLE ENERGY

By metabolizable energy is understood the total chemical energy of the feed, as measured by its heat of combustion, minus the chemical energy lost in the feces, urine, and combustible gases. In other words, it is the amount of energy capable of conversion into other forms in the body. Correcting the observed energy of the urine to a state of nitrogen equilibrium¹ the following results (Table X) may be computed as in the case of digestibility. Averages have also been computed omitting the results of period 3.

¹ By adding 7.45 Calories for each gram of nitrogen retained by the animal or subtracting the same amount or each gram of body nitrogen lost, the correction being regarded as representing energy of excretory material temporarily retained in the body.

TABLE X.—Losses of chemical energy; metabolizable energy

Feed and period.	Energy per kilogram of dry matter.					Metabolizable energy per kilogram digestible organic matter.	Percentage losses.			Percentage metabolizable.
	Total.	Losses.			Metabolizable.		In feces.	In urine.	In methane.	
		In feces.	In urine. ^a	In methane.						
ALFALFA HAY.										
Period 5.....	Cal. 4,333	Cal. 1,875	Cal. 252	Cal. 293	Cal. 1,913	Cal. 3,516	43.27	5.82	6.76	44.15
Period 6.....	4,335	1,840	255	289	1,951	3,507	42.45	5.87	6.67	45.01
Period 7.....	4,335	1,792	270	302	1,971	3,490	41.35	6.22	6.96	45.47
Weighted averages.	4,334	1,846	257	293	1,938	3,507	42.60	5.92	6.77	44.71
ALFALFA HAY AND STARCH.										
Period 1.....	4,267	1,395	166	341	2,365	3,596	32.70	3.90	7.98	55.42
Period 3.....	4,306	1,465	180	393	2,268	3,509	34.02	4.20	9.12	52.66
Period 2.....	4,306	1,353	193	398	2,362	3,516	31.43	4.49	9.26	54.82
Period 4.....	4,266	1,345	204	448	2,269	3,368	31.51	4.78	10.51	53.20
Weighted averages.	4,284	1,400	180	378	2,326	3,530	32.68	4.20	8.82	54.30
Weighted averages for periods 1, 2, and 4.....	4,276	1,376	179	373	2,348	3,538	32.18	4.19	8.72	54.91
COMPUTED FOR STARCH.										
Period 1.....	4,105	296	-53	456	3,406	3,707	7.22	-1.30	11.10	82.98
Period 3.....	4,105	487	-12	623	3,007	3,474	11.86	-0.29	15.19	73.24
Period 2.....	4,105	116	34	541	3,314	3,495	2.84	0.83	15.62	80.71
Period 4.....	4,105	134	76	823	3,072	3,182	3.25	1.86	20.05	74.84
Weighted averages.	4,105	293	-11	579	3,244	3,541	7.14	-0.24	14.10	79.03
Weighted averages for periods 1, 2, and 4.....	4,105	224	-10	563	3,328	3,563	5.46	-0.24	13.71	81.07
Kellner's average....	4,152	731	-27	382	3,066	3,603	17.61	-0.66	9.21	73.84

^a Corrected to N equilibrium.

It has already been noted that with the exception of period 3 the digestibility increased as the total amount of the ration was decreased. The converse of this is shown in Table X, of course, in the decreased losses in the feces. On the other hand, the losses in the urine and methane show a distinct increase on the lower rations. As in previous experiments, the greater digestibility of the smaller rations was apparently due largely to the greater extent of the methane fermentation accompanied by the excretion of more katabolic products of some sort in the urine. As a consequence, the metabolizable energy per kilogram of digested dry matter

or of digested organic matter was somewhat less on the lighter rations despite their higher digestibility. The difference would be still more marked if account were taken of the fact that on the lighter rations, a larger proportion of the metabolizable energy is accounted for by the heat of fermentation of the carbohydrates.

The metabolizable energy per kilogram of digested organic matter agrees closely with the results obtained by us¹ in earlier experiments on roughage and by Kellner² in his experiments on starch.

HEAT EMISSION AND PRODUCTION

The results of the measurements of heat emission are contained in Table 5 of the Appendix. The heat emission, however, does not usually correspond with the heat production.

First, any matter gained by the body is raised from the temperature of the calorimeter to the temperature of the body and a corresponding amount of the heat produced is stored up as heat in this added material.

Second, a rise in body temperature while the animal is in the calorimeter likewise absorbs a certain amount of the heat actually produced. Both these amounts must therefore be added to the heat emission to get the real heat production. Of course this correction may be negative—that is, a fall of body temperature or a loss of body weight gives a negative correction—so that in such a case the heat production is less than the heat emission. The corrections due to these two causes are shown in the Appendix, Tables 6 and 7, while Table 8 shows the heat emission, the corrections, the heat production as thus computed and also the heat production as computed in the usual way from the balance of nitrogen and carbon—that is, by indirect calorimetry.

CORRECTION FOR STANDING AND LYING

Standing as compared with lying exerts such a marked influence upon the metabolism of cattle that it is necessary to make a correction for this factor in order to render the different periods of an experiment comparable. The heat production has therefore been computed to 12 hours each standing and lying in the manner described in a previous paper.³ On using the same corrections as before for body gain and body temperature the results are as shown in Table XI.

¹ ARMSBY, H. P., and FRIES, J. A. NET ENERGY VALUES OF FEEDING STUFFS FOR CATTLE. *In Jour. Agr. Research*, v. 3, no. 6, p. 451. 1915.

ENERGY VALUES OF HOMINY FEED AND MAIZE MEAL FOR CATTLE. *In Jour. Agr. Research*, v. 10, no. 12, p. 605. 1917.

and BRAMANN, W. W. ENERGY VALUES OF RED-CLOVER HAY AND MAIZE MEAL. *In Jour. Agr. Research*, v. 7, no. 9, p. 382.

² ARMSBY, H. P. THE NUTRITION OF FARM ANIMALS. p. 301. New York, 1917.

and FRIES, J. A. OP. CIT., 1915, p. 452.

³ ARMSBY, H. P., and FRIES, J. A. OP. CIT., 1915, p. 454.

TABLE XI.—Daily heat production computed to 12 hours' standing and lying.

Period and ration.	First day.	Second day.	Mean.
ALFALFA HAY.			
Period 5.....	Calories. 13,309	Calories. 13,187	Calories. 13,248
Period 6.....	10,940	11,512	11,226
Period 7.....	8,981	8,747	8,864
ALFALFA HAY AND STARCH.			
Period 1.....	16,394	15,635	16,015
Period 3.....	11,283	11,439	11,361
Period 2.....	10,150	9,689	9,920
Period 4.....	8,483	8,325	8,404

ENERGY EXPENDITURE CONSEQUENT UPON FEED CONSUMPTION

The heat production in this experiment shows the same marked dependence upon the amount of feed consumed which has been noted in all previous investigations. By a difference computation, the heat increment caused by a unit of feed consumed may be computed. For example, a comparison of periods 5 and 7 gives the following results:

TABLE XII.—Example of computation of heat increment due to feed

Period.	Dry matter eaten.	Heat production.
	Gm.	Calories.
Period 5.....	7,893	13,248
Period 7.....	3,502	8,864
Difference.....	4,391	4,384
Difference per kilogram of dry matter.....		999

TABLE XIII.—Heat increment per kilogram of dry matter

Feed and period.	Heat production per kilo.	Feed and period.	Heat production per kilo.
ALFALFA HAY.		ALFALFA HAY AND STARCH—CON.	
Periods 5-6.....	Cal. 1,146	Periods 1-4.....	Cal. 1,200
Periods 6-7.....	899	STARCH.	
Periods 5-7.....	999	Periods 1-3.....	2,118
ALFALFA HAY AND STARCH.		Periods 3-2.....	762
Periods 1-3.....	1,321	Periods 2-4.....	1,649
Periods 3-2.....	931	Periods 1-2.....	1,704
Periods 2-4.....	1,192	Periods 1-4.....	1,692
Periods 1-2.....	1,202		

In the same manner the heat increment per kilogram of the mixed ration of hay and starch may be computed, while by a comparison of these results with those on hay the energy expenditure per kilogram of

starch may be calculated. Three comparisons are obviously possible on the hay and five on the mixed ration. The results are contained in Table XIII.

It may be presumed that, other things being equal, the results obtained by comparing the extreme periods—namely, periods 5 and 7 for hay and periods 1 and 4 for the mixed ration—will be the most accurate. In the case of the hay the intermediate comparisons show differences similar to those already reported.^a In the case of the mixed ration and of the starch the results show a marked degree of uniformity with the exception of those involving period 3. As already noted, the results of this period as regards digestibility, methane production, and metabolizable energy appear somewhat abnormal as compared with those of periods 1, 2, and 4, the losses in feces and methane being relatively large and the percentage of the gross energy which was metabolizable being correspondingly lower. This might be expected to result in a lower heat production. If such were the fact, it would tend to explain the marked divergence of those heat increments in Table XIII which involve the use of period 3. We are inclined therefore to accept the results of the extreme periods—viz,

Hay.....	999 Calories per kilogram
Hay and starch.....	1,200 Calories per kilogram
Starch.....	1,692 Calories per kilogram

as representing most accurately the heat increment caused by the consumption of these materials.

NET ENERGY VALUES

Subtracting from the gross energy the losses of chemical energy and the heat increment due to feed consumption gives the net energy value as follows (Table XIV):

TABLE XIV.—Net energy values per kilogram of dry matter

Feed and period.	Gross energy.	Losses of chemical energy.	Metabolizable energy.	Heat increment.	Net energy values.	Net metabolizable.
ALFALFA HAY.						
Average.....	Cal. 4,334	Cal. 2,396	Cal. 1,938	Cal. b 999	Cal. 939	Per ct. 48.45
ALFALFA HAY AND STARCH.						
Average of all.....	4,284	1,958	2,326	c 1,200	1,126	48.41
Average of periods 1, 2, and 4..	4,276	1,928	2,348	c 1,200	1,148	48.89
STARCH.						
Average of all.....	4,105	861	3,244	c 1,692	1,552	47.84
Average of periods 1, 2, and 4..	4,105	777	3,328	c 1,692	1,636	49.16
Kellner's average.....	4,152	1,101	3,051	1,248	1,803	58.80

^a ARMSBY, H. P., and FRIES, J. A. OP. CIT., 1915, p. 473-475.^b From results of periods 5 and 7.^c From results of periods 1 and 4.

COMPARISON WITH KELLNER'S RESULTS ON STARCH

As noted at the beginning of this article, Kellner has reported a number of determinations of the net energy of starch. His results, expressed in terms of energy and computed in a somewhat different manner than that used by Kellner himself,¹ are included in Table XIV. Two marked differences appear. Kellner's metabolizable energy is lower than that found in our experiment, while his heat increment is also less, the net result being a higher net energy value. Kellner's rations, however, differ quite materially from ours. As regards quantity (total organic matter) our mixed ration was considerably above Kellner's in period 1 and much below it in periods 2 and 4. As regards make-up it contained a much larger proportion of hay and no concentrate except starch. The percentage of starch in the total ration was 31.2 as against 19.2 in Kellner's, but the percentage of organic matter supplied by the hay was 69.8 as compared with 40.9 in Kellner's experiments. As regards nutritive ratio our ration was somewhat narrower than three of Kellner's rations and somewhat wider than the other two.

The difference in the metabolizable energy is due chiefly to a much larger loss in the feces in Kellner's experiments, as Table X shows. If this be eliminated, by computing the losses in urine and methane upon the digested energy the following comparisons are obtained:

TABLE XV.—Distribution of digested energy of starch

	In urine.	In methane	Metabolizable.
	Per cent.	Per cent.	Per cent.
Mean of periods 1, 2, and 4.....	—0.26	14.50	85.76
Kellner's mean.....	— .79	11.17	89.62

The higher digestibility of the starch in our experiment was accompanied (caused?) by a greater production of methane, so that a less proportion of the digested energy was metabolizable. When thus computed on the digested energy, our results in period 1 agree substantially with Kellner's, while periods 2 and 4 show a considerably greater relative loss of energy in the methane. Period 3, as already noted, appears exceptional. No obvious explanation presents itself for the high heat increment found in our experiment. The more extensive fermentation of the starch may perhaps account for a portion, but by no means all of it.

¹ ARMSBY, H. P. OP. CIT., 1917, p. 455-459, 474.

SUMMARY

In seven respiration calorimeter experiments on a steer the digestibility and metabolizable energy of different amounts of alfalfa hay and of a mixture of alfalfa hay and commercial starch the gaseous excretion and the heat production were determined.

By a comparison of periods in which different amounts of the same ration were fed, the heat increments consequent on feed consumption and the net energy values of the rations were computed.

The digestibility of the rations, the losses in the urine, and the extent of the methane fermentation showed a distinct increase as the total amount of the ration was reduced.

The greater loss of energy in the urine and methane on the lighter rations more than compensated for the smaller losses in the feces, so that the proportion of the total energy metabolizable was somewhat less than on the heavier rations.

The metabolizable energy of the starch was 10 per cent greater than the average computed from five experiments by Kellner, the difference being due chiefly to smaller losses in the feces. Starch caused the usual depression in digestibility.

The average heat increment caused by the consumption of alfalfa hay was 999 Calories per kilogram of dry matter as compared with 981 Calories found for the same hay in the previous year and with an average of 1,169 Calories in six previous experiments on three different samples.

The average heat increment for the starch was 1,692 Calories per kilogram of dry matter as compared with 1,248 Calories computed from Kellner's experiments.

The net energy values of the starch was about 9 per cent lower than that computed from Kellner's experiments, only 49 per cent, as compared with 59 per cent of the metabolizable energy being utilized by the animal.

APPENDIX

The principal numerical data obtained in the experiments are recorded in the following tables. The computations involved have been carried out beyond the probable limit of accuracy of the experimental methods in order to guard against a possible accumulation of arithmetical errors.

TABLE 1.—Digestibility of rations

Feed and period.	Dry matter.	Ash.	Organic matter.	Protein.	Non-protein.	Crude fiber.	N-free extract.	Ethe extract.	Total nitrogen.	Carbon	Energy.
ALFALFA HAY.											
Period 5:	Gm.	Gm.	Gm.	Gm.	Gm.	Gm.	Gm.	Gm.	Gm.	Gm.	Calories.
Total fed.....	7,893.0	732.0	7,161.0	896.9	238.9	2,325.5	3,502.5	137.2	194.3	3,550.3	34,198.95
Feces.....	3,297.6	431.6	2,866.0	297.2	30.7	1,366.5	1,056.3	115.3	53.3	1,528.7	14,796.30
Amount digested..	4,595.4	300.4	4,295.0	599.7	208.2	959.0	2,506.2	21.9	141.0	2,021.6	19,402.65
Percentage digest- ibility.....	58.22	41.04	59.98	66.86	87.15	41.24	70.35	15.96	72.57	56.94	56.73
Period 6:											
Total fed.....	6,127.8	577.9	5,549.9	705.5	190.9	1,836.1	2,709.1	108.2	153.5	2,741.3	26,561.99
Feces.....	2,482.4	341.4	2,141.0	217.2	20.2	1,026.9	778.3	98.5	42.0	1,162.7	11,276.20
Amount digested..	3,645.4	236.5	3,408.9	488.3	170.7	809.2	1,930.8	9.7	111.5	7,578.6	15,285.79
Percentage digest- ibility.....	59.49	40.92	61.42	69.21	89.52	44.07	71.27	8.96	72.64	57.59	57.55
Period 7:											
Total fed.....	3,501.6	330.2	3,171.4	403.1	109.1	1,049.2	1,548.1	61.8	87.7	1,566.4	15,178.28
Feces.....	1,384.2	190.5	1,193.7	122.8	10.2	580.1	432.8	47.9	23.2	647.9	6,276.31
Amount digested..	2,117.4	139.7	1,977.7	280.3	98.9	469.1	1,115.3	13.9	64.5	918.5	8,901.97
Percentage digest- ibility.....	60.47	42.31	62.36	69.54	90.65	44.71	72.04	22.49	73.55	58.65	58.65
ALFALFA HAY AND STARCH.											
Period 1:											
Alfalfa hay.....	6,629.3	646.0	5,983.3	752.0	216.8	2,034.4	2,858.4	121.8	166.5	2,983.2	28,740.3
Starch.....	2,729.1	6.7	2,722.4	9.5	.....	3.4	2,709.5	.....	1.6	1,191.0	11,202.5
Total fed.....	9,358.4	652.7	8,705.7	761.5	216.8	2,037.7	5,567.9	121.8	168.1	4,174.2	39,942.8
Refused.....	537.4	40.4	497.0	42.3	12.9	223.1	211.9	6.8	9.5	241.6	2,303.7
Amount eaten.....	8,821.0	612.3	8,208.7	719.2	203.9	1,814.6	5,356.0	115.0	158.6	3,932.6	37,639.1
Feces.....	2,746.8	339.6	2,407.2	287.4	25.2	1,102.2	904.4	87.9	58.7	1,272.7	12,307.6
Amount digested..	6,074.2	272.7	5,801.5	431.8	178.7	712.4	4,451.6	27.1	99.9	2,659.9	25,331.5
Percentage digest- ibility.....	68.86	44.54	70.68	60.04	87.64	39.26	83.11	23.57	62.99	67.64	67.30
Period 3:											
Alfalfa hay.....	3,747.7	330.8	3,416.9	410.6	120.3	1,194.1	1,625.8	66.1	91.3	1,684.3	16,452.03
Starch.....	1,551.1	3.8	1,547.3	5.4	.....	1.9	1,540.0	.....	.9	676.9	6,367.03
Total eaten.....	5,298.8	334.6	4,964.2	416.0	120.3	1,196.0	3,165.8	66.1	92.2	2,361.2	22,819.06
Feces.....	1,710.0	171.1	1,538.9	182.5	13.4	695.5	595.3	52.1	34.3	801.9	7,763.81
Amount digested..	3,588.8	163.5	3,425.3	233.5	106.9	500.5	2,570.5	14.0	57.9	1,559.3	15,055.25
Percentage digest- ibility.....	67.73	48.86	69.00	56.13	88.86	41.85	81.20	21.18	62.80	66.04	65.98
Period 2:											
Alfalfa hay.....	2,645.4	233.5	2,411.9	289.8	84.9	842.9	1,148.3	46.6	64.44	1,188.9	11,613.04
Starch.....	1,105.0	2.7	1,102.3	3.8	.....	1.4	1,097.1	.....	.6	482.2	4,535.86
Total eaten.....	3,750.4	236.2	3,514.2	293.6	84.9	844.3	2,245.4	46.6	65.0	1,671.1	16,148.90
Feces.....	1,120.6	124.2	996.4	111.8	9.7	464.7	372.0	38.3	21.9	522.4	5,075.81
Amount digested..	2,629.8	112.0	2,517.8	181.8	75.2	379.6	1,873.4	8.3	43.1	1,148.7	11,073.09
Percentage digest- ibility.....	70.12	47.42	71.65	61.92	88.57	44.96	83.43	17.81	66.31	68.74	68.57
Period 4:											
Alfalfa hay.....	1,754.0	162.7	1,591.3	199.3	53.1	516.8	791.7	30.5	43.2	788.9	7,599.76
Starch.....	726.0	1.8	724.2	2.5	.....	.9	720.8	.....	.4	316.8	2,980.12
Total eaten.....	2,480.0	164.5	2,315.5	201.8	53.1	517.7	1,512.5	30.5	43.6	1,105.7	10,579.88
Feces.....	728.9	84.5	644.4	74.4	6.0	296.1	240.7	27.1	15.4	343.3	3,334.40
Amount digested..	1,751.1	80.0	1,671.1	127.4	47.1	221.6	1,271.8	3.4	28.2	762.4	7,245.48
Percentage digest- ibility.....	70.61	48.63	72.17	63.13	88.70	42.80	84.09	11.15	64.68	68.9	68.48

TABLE 2.—Urinary excretion

Feed and period.	Weight.	Average specific gravity.	Total solids.		Total nitrogen.		Total carbon.		Energy.	
									Per gram.	Total.
ALFALFA HAY.										
Period 5:	Gms.		Per cent.	Gms.	Per cent.	Gms.	Per cent.	Gms.	Calo-ries.	Calories.
Collected.....	95,884	1.041	8.26	7,920.0	1.347	1,291.6	2.040	1,956.0	.1990	19,080.9
Spilled.....	1,245			33.1		5.4		8.2		79.8
Total, 10 days.....	97,129			7,953.1		1,297.0		1,964.2		19,160.7
Average.....	9,712.9			795.3		129.7		196.4		1,916.1
Period 6:										
Collected.....	90,763	1.035	6.08	5,518.4	1.097	995.7	1.647	1,494.9	.1619	14,694.5
Spilled.....	1,451			75.4		13.6		20.4		200.7
Total, 10 days.....	92,214			5,593.8		1,009.3		1,515.3		14,895.2
Average.....	9,221.4			559.4		100.9		151.5		1,489.5
Period 7:										
Collected.....	66,059	1.068	6.01	3,970.1	1.068	705.5	1.631	1,077.4	.1510	9,974.9
Average.....	6,605.9			397.0		70.6		107.7		997.5
ALFALFA HAY AND STARCH.										
Period 1:										
Collected.....	68,544	1.044	8.768	6,009.9	.948	649.8	1.995	1,367.5	.1745	11,960.9
Spilled.....	2,943			157.2		17.9		37.7		329.5
Total, 10 days.....	71,487			6,167.1		667.7		1,405.2		12,290.4
Average.....	7,148.7			616.7		66.7		140.5		1,229.0
Period 3:										
Collected.....	71,192	1.0302	4.45	3,168.0	.696	495.5	1.406	1,001.0	.1263	8,991.5
Spilled.....	805			12.1	.238	1.9		3.8		34.5
Total, 10 days.....	71,997			3,180.1		497.4		1,004.8		9,026.0
Average.....	7,199.7			318.0		49.7		100.5		902.6
Period 2:										
Collected, 10 days.....	60,057	1.030	5.586	3,354.8	.718	431.2	1.304	783.1	.1221	7,333.0
Average.....	6,005.7					43.1		78.3		733.3
Period 4:										
Collected, 10 days.....	39,042	1.0308	5.533	2,160.2	.899	351.0	1.506	588.0	.1447	5,649.4
Average.....	3,904.2			216.0		35.1		58.8		564.9

TABLE 3.—Average daily production of epidermal tissue

Factor.	In growth of hair.	In brush-ings.	Total.
Dry matter.....	gm.. 2.20	9.19	11.39
Nitrogen.....	gm.. 0.33	.73	1.06
Carbon.....	gm.. 1.09	3.96	5.05
Energy.....	Cal.. 11.99	43.13	55.12

TABLE 4.—Gaseous excretion

Feed and period.	Water.	Carbon dioxid.	In combustible gases.		Methane computed from car- bon.	Ratio, hydrogen to carbon.
			Hydro- gen.	Carbon.		
ALFALFA HAY.						
Period 5:	Gm.	Gm.	Gm.	Gm.	Gm.	
First day.....	7,101.04	5,570.91	43.35	132.19	176.65	3.049
Second day.....	6,889.56	5,439.04	41.44	127.01	169.72	3.065
Average.....	6,995.30	5,504.98	42.40	129.60	173.19	3.057
Period 6:						
First day.....	5,570.20	4,597.76	34.00	102.50	136.96	3.015
Second day.....	5,341.17	4,539.40	32.89	96.17	128.51	2.924
Average.....	5,458.69	4,568.58	33.45	99.34	132.74	2.970
Period 7:						
First day.....	3,525.93	3,266.36	29.39	60.30	80.57	2.052
Second day.....	3,394.18	3,238.68	22.89	58.22	77.80	2.543
Average.....	3,460.06	3,252.52	26.14	59.26	79.19	2.267
ALFALFA HAY AND STARCH.						
Period 1:						
First day.....	10,423.97	7,068.02	56.18	172.75	230.85	3.075
Second day.....	9,632.29	7,022.94	53.61	164.20	219.43	3.063
Average.....	10,028.13	7,045.48	54.90	168.48	225.14	3.069
Period 3:						
First day.....	5,257.87	4,732.27	37.28	115.62	154.50	3.101
Second day.....	5,247.31	4,717.45	38.19	117.76	157.36	3.084
Average.....	5,252.59	4,724.86	37.74	116.69	155.93	3.092
Period 2:						
First day.....	4,559.94	3,929.83	26.86	82.98	110.88	3.089
Second day.....	4,208.61	3,889.07	27.36	84.65	113.11	3.094
Average.....	4,384.28	3,903.45	27.11	83.82	112.00	3.092
Period 4:						
First day.....	3,175.56	3,158.00	20.03	63.16	84.39	3.153
Second day.....	3,161.98	3,109.36	19.62	61.57	82.28	3.138
Average.....	3,168.77	3,133.68	19.83	62.37	83.34	3.145

TABLE 5.—Heat emission

Feed and period.	By radiation and conduction.	As latent heat of water vapor.	Total.
ALFALFA HAY.			
Period 5:	Calories.	Calories.	Calories.
First day.....	8,812.59	4,100.60	12,913.28
Second day.....	8,651.67	4,039.94	12,691.61
Average.....	8,732.13	4,070.32	12,802.45
Period 6:			
First day.....	7,742.57	3,273.23	11,015.80
Second day.....	7,661.46	3,152.17	10,813.63
Average.....	7,702.02	3,212.70	10,914.72
Period 7:			
First day.....	6,120.28	2,082.40	8,202.68
Second day.....	6,271.53	1,996.61	8,268.14
Average.....	6,195.91	2,039.51	8,235.41

TABLE 5.—Heat emission—Continued

Feed and period.	By radiation and conduction.	As latent heat of water vapor.	Total.
ALFALFA HAY AND STARCH.			
Period 1:	Calories.	Calories.	Calories.
First day.....	10,731.85	4,860.76	15,592.61
Second day.....	10,619.21	4,887.53	15,506.74
Average.....	10,675.53	4,874.15	15,549.67
Period 3:			
First day.....	7,744.58	3,086.37	10,830.95
Second day.....	7,770.84	3,071.71	10,842.55
Average.....	7,757.71	3,079.04	10,836.75
Period 2:			
First day.....	7,075.60	2,583.70	9,659.30
Second day.....	6,986.47	2,457.77	9,444.24
Average.....	7,031.04	2,520.73	9,551.77
Period 4:			
First day.....	6,108.95	1,880.96	7,989.91
Second day.....	6,102.51	1,862.38	7,964.89
Average.....	6,105.73	1,871.67	7,977.4

TABLE 6.—Corrections of heat emission for gains by body^a

Feed and period.	Gain—			Mean body tempera- ture.	Calorime- ter tem- perature.	Correc- tion.
	Protein. ^b	Fat.	Water.			
ALFALFA HAY.						
Period 5:	Gm.	Gm.	Gm.	°C.	°C.	Cal.
First day.....	+ 61.2	+178.4	-8,558			-176
Second day.....	+ 61.2	+232.3	+2,513			+ 56
Average.....	+ 61.2	+205.3	-3,022	38.58	17.66	- 60
Period 6:						
First day.....	+ 57.0	+ 46.0	-9,393			-197
Second day.....	+ 57.0	+ 75.8	+1,242			+ 28
Average.....	+ 57.0	+ 60.9	-4,076	38.70	17.67	- 85
Period 7:						
First day.....	- 43.2	-160.2	- 604			- 15
Second day.....	- 43.2	-147.7	- 52			- 3
Average.....	- 43.2	-154.0	- 328	38.00	17.71	- 9
ALFALFA HAY AND STARCH.						
Period 1:						
First day.....	+192.0	+409.2	-7,403			-148
Second day.....	+192.0	+436.5	+5,938			+131
Average.....	+192.0	+422.9	- 733	38.67	17.76	- 8
Period 3:						
First day.....	+ 42.6	+ 32.9	-3,634			- 75
Second day.....	+ 42.6	+ 35.3	+1,117			+ 25
Average.....	+ 42.6	+ 34.1	-1,259	38.50	17.69	- 25
Period 2:						
First day.....	- 6.6	-112.3	-1,480			- 32
Second day.....	- 6.6	-100.0	- 369			- 9
Average.....	- 6.6	-106.2	- 924	38.28	17.72	- 21
Period 4:						
First day.....	- 48.0	-262.3	+ 102			- 2
Second day.....	- 48.0	-242.8	-1,099			- 26
Average.....	- 48.0	-252.6	- 499	38.14	17.72	- 14

^a Estimated specific heats; protein 0.30, fat 0.66.^b Average of entire digestion period.

TABLE 7.—Corrections of heat emission for changes of body temperature in 48 hours

Feed and period.	Live weight when leaving calorimeter.	Body temperature. ^a			Corrections for body temperature. ^b
		Entering.	Leaving.	Difference.	
ALFALFA HAY.					
	<i>Kgm.</i>	<i>°C.</i>	<i>°C.</i>	<i>°C.</i>	<i>Cal.</i>
Period 5.....	423.2	38.33	38.83	+0.50	+169
Period 6.....	412.2	38.67	38.72	+0.05	+16
Period 7.....	383.0	37.44	38.56	+1.12	+343
ALFALFA HAY AND STARCH.					
Period 1.....	409.8	38.67	38.67	0.00	0
Period 3.....	374.4	38.33	38.67	+0.34	+108
Period 2.....	398.0	38.22	38.33	+0.11	+33
Period 4.....	364.7	37.94	38.33	+0.39	+114

^a Taken in Fahrenheit degrees and reduced.^b Specific heat of body, 0.8.

TABLE 8.—Daily heat production

Feed and period.	Heat emission.	Correc- tion for body tempera- ture ^a (Table 7).	Correc- tion for body gain per day (Table 6).	Observed heat pro- duction.	Com- puted heat pro- duction.	Com- puted + observed.
ALFALFA HAY.						
Period 5:	Calories.	Calories.	Calories.	Calories.	Calories.	Per cent.
First day.....	12,913.3	+ 85	-176	12,822.3	13,030.7	101.6
Second day.....	12,691.6	+ 85	+ 56	12,832.6	12,611.1	98.3
Average.....	12,802.5	+ 85	- 60	12,827.5	12,820.9	99.9
Period 6:						
First day.....	11,015.8	+ 8	-197	10,826.8	11,144.1	102.9
Second day.....	10,813.6	+ 8	+ 28	10,849.6	10,981.4	101.2
Average.....	10,914.7	+ 8	- 85	10,837.7	11,062.8	102.0
Period 7:						
First day.....	8,202.7	+172	- 15	8,359.7	8,542.4	102.2
Second day.....	8,268.1	+172	- 3	8,437.1	8,460.6	100.3
Average.....	8,235.4	+172	- 9	8,398.4	8,501.5	101.2
ALFALFA HAY AND STARCH.						
Period 1:						
First day.....	15,592.6	0	-148	15,444.6	15,985.1	103.5
Second day.....	15,506.7	0	+131	15,637.7	15,878.1	101.5
Average.....	15,549.7	0	- 8	15,541.7	15,931.6	102.5
Period 3:						
First day.....	10,831.0	+ 54	- 75	10,810.0	11,420.8	105.6
Second day.....	10,842.6	+ 54	+ 25	10,921.6	11,419.6	104.6
Average.....	10,836.8	+ 54	- 25	10,865.8	11,420.2	105.1
Period 2:						
First day.....	9,659.3	+ 16	- 32	9,643.3	9,909.6	102.8
Second day.....	9,444.2	+ 16	- 9	9,451.2	9,763.0	103.3
Average.....	9,551.8	+ 16	- 21	9,546.8	9,836.3	103.0
Period 4:						
First day.....	7,989.9	+ 57	- 2	8,044.9	8,264.9	102.7
Second day.....	7,964.9	+ 57	- 26	7,995.9	8,107.8	101.4
Average.....	7,977.4	+ 57	- 14	8,020.4	8,186.4	102.0

^a Assuming the correction for 48 hours (Table 7) to be equally divided between the two days.

[*Reprinted from the Journal of Agricultural Science*, Vol. IX. Part II.]

[*All Rights reserved.*]

NET ENERGY VALUES AND STARCH VALUES.

BY HENRY PRENTISS ARMSBY AND J. AUGUST FRIES.

Institute of Animal Nutrition, State College, Pennsylvania.

It is now accepted as a fundamental doctrine in animal nutrition that the prime function of food is to supply energy for the operation of the human or animal body and that all its other diverse uses are essentially tributary to this main purpose. The growing recognition of this fact in its relations to the nutrition of farm animals has given rise during the past twenty-five years to extensive investigations, especially by Zuntz and his associates, by Kellner and Köhler and by the writers, in which the attempt has been made to determine experimentally how much energy the various feeding stuffs can actually contribute toward the upkeep of the animal body.

Zuntz's investigations have been chiefly upon the horse and will not be discussed here. Kellner's and our own have been upon cattle. For them the same general methods have, in the main, been used and the results have been in general accord. In the actual application of those results to practice, however, two quite diverse, although not fundamentally inconsistent, methods have been followed, with more or less resulting confusion. The matter has seemed to us to be of sufficient importance to warrant a brief contribution to the discussion of the subject and an attempt to make clear what we, at least, conceive to be the relation between the two systems.

The earlier of the two was Kellner's system of "Starch values," which before the war had obtained wide currency not only in Germany but in other countries of continental Europe and to some extent in Great Britain.

Kellner's starch values are in reality disguised energy values. In his fundamental investigations he used substantially the same general methods adopted subsequently by the writers; that is, he determined by so-called indirect calorimetry, using a Pettenkofer respiration apparatus, what part of the total energy contained in a variety of feeding stuffs could actually be recovered as gain of flesh and fat by the animal.

Furthermore, similar trials were made with nearly pure gluten, starch, cellulose, sugar and oil as representatives of the digestible protein, carbohydrates and fats of feeding stuffs, and from their results, corrected by those on actual feeding stuffs, a method was worked out for computing the energy values of materials not yet subjected to respiration experiments. The details of the method of calculation have been frequently published¹ and need not be reproduced here. The writers, following, as already stated, the same general plan of investigation but determining the actual heat production of the experimental animal as well as its respiratory products, and including experiments on submaintenance rations, have proposed² a somewhat simpler method of computation for attaining the same end.

Thus far, the two sets of values substantially parallel each other. It is in the method of expressing them for practical use in computing rations that the two systems diverge. The writers have expressed them directly in terms of energy ("Net energy values"), simply using a large unit (the *therm* = 1000 kilogram calories) to avoid the inconvenience of large numbers. Kellner, on the contrary, in view of the unfamiliar nature of energy units and of the large numbers required to express the energy values in terms of calories, was led to adopt as a substitute the equivalent amount of digested starch. Suppose, for example, that a sample of maize meal is found, either by direct experiment or by calculation, to have a net energy value of 85,200 calories per hundred pounds, or 85.2 therms, *i.e.* to be capable of contributing this amount to the upkeep of the body. According to Kellner's investigations, one pound of digestible starch has a net energy value of 1.071 therms. The 85.2 therms contained in one hundred pounds of maize meal might, then, be supplied by $85.2 \div 1.071 = 79.5$ pounds of digestible starch and the latter number is the "Starch value," in Kellner's sense, of the maize meal. In other words, so far as the energy supply to the animal is concerned one hundred pounds of the maize meal might be replaced by 79.5 pounds of digestible starch, while conversely the starch value multiplied by 1.071 gives the net energy value in therms.

Kellner's starch value may be said to be a mixed unit. It attempts to express what are really quantities of energy in terms of matter and it has always seemed to us an unfortunate and an unnecessary concession to established usage. Moreover, experience has shown that in its actual

¹ Compare Kellner, *The Scientific Feeding of Farm Animals* (Goodwin's translation), and Armsby, *The Nutrition of Farm Animals*, pp. 668-672.

² *Journ. Agr. Research*, 3 (1905), 486; *The Nutrition of Farm Animals*, pp. 673-675.

use it is not always easy, even for experts, to avoid misapprehension and confusion of thought, as some striking instances in the recent literature of the subject have shown.

MISAPPREHENSIONS REGARDING STARCH VALUES.

Kellner's starch value in its proper sense as just defined has been mistakenly identified with two quite different conceptions.

The first of these is the so-called "Carbohydrate equivalent" of the digestible nutrients. By conventional methods we determine the amounts of digestible protein, carbohydrates and fat contained in a feeding stuff and by multiplying the fat by 2.25 or a similar factor and adding the other two we compute the carbohydrate equivalent of the digested substances, or the "Total nutrients." Thus for average American alfalfa hay as reported by Henry and Morrison¹ the computation is

Digestible protein	10.6 per cent.
„ carbohydrates	39.0 „
„ fat $0.9 \times 2.25 =$	2.0 „
	51.6 „

Such a calculation, however, simply shows that the digested nutrients in one hundred pounds of the hay contain roughly the same amount of total energy as 51.6 pounds of carbohydrates, viz. about 97.9 therms. It shows nothing whatever regarding the losses of energy which occur during digestion and assimilation nor as to how much remains available to the animal. While in a sense it is a starch equivalent it is not Kellner's starch value. It shows what the hay contains but not what useful effect it can produce.

A second misapprehension identifies Kellner's starch value with what has been called the "Physiological heat value," or the "Fuel value," or what the writers have designated as the "Metabolizable energy."

It is well recognized that not all the energy contained in the digested nutrients is available to the body, but that a considerable proportion of it escapes unused in the metabolic products of the urine and in the combustible gases produced in the digestive tract. In the case of starch some 10 per cent. of its energy escapes in the methane excreted by cattle, while none of it is lost in the urine. One pound of digested starch, therefore, is capable of yielding in the form of heat in the body of a

¹ *Feeds and Feeding*, 15th ed., p. 660.

steer only 1.706 therms out of its total energy content of 1.897 therms. The mean of similar determinations shows that, after deducting the losses in urine and methane, the digestible matter of one hundred pounds of average alfalfa hay, out of its total energy content of 97.9 therms, may supply 80.8 therms of heat to the body. This is its metabolizable energy, or fuel value. But since one pound of starch can supply 1.706 therms, evidently the digestible matter of one hundred pounds of the alfalfa hay yields as much heat as $80.8 \div 1.706 = 47.37$ pounds of starch. In other words, 47.37 pounds of digested starch, instead of 51.6 pounds, would be equivalent as body fuel to one hundred pounds of the hay.

This figure evidently approximates more nearly to expressing a physiological value than the previous one, but even this reduced value does not measure the actual contribution which the hay can make to the nutrition of the animal, since it fails to take account of the very considerable amount of energy expended in the mechanical and chemical processes incident to the consumption, digestion and assimilation of the feed. It was precisely the special merit of Kellner's researches that they covered this point. He measured the actual amount of energy utilized by the animal and demonstrated that it was notably less, not only than the carbohydrate equivalent of the digested nutrients but also less than the physiological heat value, or fuel value, or metabolizable energy of these nutrients.

Moreover, not only is the utilizable or "Net" energy of a feeding stuff less than its fuel value, or metabolizable energy, but the two are not even approximately proportional. In Kellner's investigations, as summarized by the senior author¹, the percentage of the metabolizable energy which was actually utilized ranged, in round numbers, from 18 per cent. in wheat straw to 66 per cent. in cotton seed meal while in our own experiments there was a similar range from 45 per cent. in maize stover to 61 per cent. in hominy feed. In other words, to supply as much metabolizable energy as 100 pounds of hominy feed would require 180 pounds of maize stover, but to supply as much net, or utilizable, energy as 100 pounds of hominy feed would require 243 pounds of maize stover.

Kellner's starch values were intended to express the net, or utilizable, energy of the feed and not its content of carbohydrates nor its fuel value. Thus the starch value of average alfalfa hay, computed by Kellner's method, is 34.5 pounds per hundred, equivalent to 36.9 therms of net

¹ *The Nutrition of Farm Animals*, p. 660.

energy or to 45.7 per cent. of the fuel value, while by the writers' method of computation the net energy would be still less, viz., 32.3 therms.

MAINTENANCE AND PRODUCTION VALUES.

Perhaps the most prolific source of confusion in the discussion of starch values and energy values has been the fact that Kellner, in his earlier publications, assumed that the fuel values, or metabolizable energy, of feeding stuffs as determined by him represented their values for maintenance. This was in accord with the notion then current and still more or less widely held according to which the chief energetic function of the maintenance ration is to supply heat to support the normal body temperature.

Were such the case, it is evident that a feeding stuff would have two distinct energy values, or starch values. Of these, the larger, equal to its fuel value, or metabolizable energy, would express its value for maintenance while the smaller, or net energy value, would represent its value for production. Such a dualistic system would introduce most perplexing complications into all comparisons of rations, but in fact it lacks any adequate experimental foundation. No such sharp contrast has been shown to exist between maintenance and production and the prevention of loss of tissue in the former and the deposition of new tissue in the latter appear to be substantially similar in their energetic aspects.

The writers were the first to show¹ in 1902 that with cattle consuming submaintenance rations only about 60 per cent. of the metabolizable energy of timothy hay actually contributed to the maintenance of the animal, i.e. to the prevention of the loss of body substance, while the remaining 40 per cent. simply increased his heat production, which was already sufficient to maintain his body temperature. In other words, it was shown that, qualitatively at least, the relations were the same as in Kellner's experiments on fattening.

Repeated subsequent experiments have abundantly confirmed this result². Together with the almost simultaneous investigations of Rubner and the later ones of Lusk and others on the so-called specific dynamic action of foods they have rendered it evident that, under most conditions, heat production is not an end but an incident of metabolism. The body usually does not metabolize because it must produce heat

¹ U.S. Dept. of Agr., Bur. Anim. Indus., *Bull.* No. 51.

² Compare *The Nutrition of Farm Animals*, pp. 271-272.

but produces heat because it metabolizes. In his later writings¹ Kellner fully accepted this view and distinguished in feeding stuffs between "Thermic" energy, which can only yield heat in the body, and "Dynamic" energy (equivalent to our net energy), which is available for physiological processes, and pointed out that what is required for maintenance is not a supply of thermal energy equal to the minimum heat loss from the body but a supply of dynamic energy sufficient to support the necessary bodily activities.

Such being the case, it is clear that in maintenance as in productive feeding only a part of the metabolizable energy of the feed is utilized, except perhaps at unusually low temperatures. Whether the proportion which can be utilized is the same in the two cases it is perhaps too early to assert positively. Certain theoretical considerations might lead one to suppose that it would be somewhat greater in maintenance than in production, but within the range of our own experiments² the results, although somewhat variable, do not on the whole indicate that the difference can be great and we are inclined to believe that the same starch values, or net energy values, are applicable without material error to estimating the values of feeding stuffs both for the maintenance and the fattening of cattle and presumably of other species of ruminants.

To recapitulate, then, Kellner's starch values represent neither the digestible carbohydrates (actual or potential) contained in feeding stuffs nor the fuel value of the material which they supply to the tissues. What they seek to express in another form is precisely what we have expressed in our net energy values, viz., the extent to which the feed is able, either to diminish or prevent loss of stored energy from the body (submaintenance and maintenance rations) or to bring about a storage of energy in new tissue (fattening, growth, etc.). Aside from experimental errors, there is no difference in principle between the two sets of values but merely a difference in the manner of expression. It may be presumed that whichever of the two is on the whole preferable will survive, but in view of the various senses in which the term starch value may be used we feel that there are at least certain manifest advantages in frankly accepting the fact that we are dealing with the feed as a source of energy and in employing a recognized unit of energy to express its value.

¹ Compare *Ernährung landw. Nutztiere*, 6th ed., pp. 105-109.

² *Journ. Agr. Research*, 3 (1915), 472.

(Received January 17th, 1919.)

[Reprinted from SCIENCE, N. S., Vol. L., No. 1289,
Pages 242-244, September 12, 1919]

A NATIONAL INSTITUTE OF NUTRITION

IN a recent issue of SCIENCE (August 1, 1919) Lusk calls attention to a reconstruction problem which seems in danger of receiving less consideration than its fundamental significance demands, viz., the food problem, vital to the very existence of civilization, and proposes as one agency for its study the foundation of a national laboratory of human nutrition. The importance of the subject is such that Lusk's proposal seems to invite discussion on the part of those more or less directly interested in the science of nutrition and its utilization for the benefit of humanity. Accordingly I venture to submit for consideration certain personal notions regarding the kind of organization which is desirable and as to steps which might be taken to secure it.

It is to be remarked in the first place that the subject of national (and still more of international) nutrition is a very broad one, involving much more than the mere laboratory study of the laws of human nutrition, important as that is. It is a two-fold subject, including the economical production of food as well as its efficient utilization. The farmer, like other producers, rightly desires a reasonable reward for his services. The interests of the consuming public demand a liberal food supply at prices low enough to ensure the adequate nourishment of all classes of the community. It should be the aim of any national organization of students of nutrition to contribute to the harmonizing of these apparently conflicting interests and to demon-

strating that in the large view they are not antagonistic. Accordingly I feel inclined to broaden the caption of Lusk's article and to speak provisionally of a national institute of nutrition.

In the organization of such an institute there are certain general principles which should, as I think, control.

1. It should not be burdened with executive duties. Questions of transportation, marketing, cold storage, profiteering, price control, rationing, etc., should be recognized as subjects lying outside its field and with which students of nutrition as such are not specially qualified to deal. In brief, it should not be an executive department of the government nor have the functions of a food administration but should supply to legislative and executive authorities the scientific data upon which any successful measures of food policy must be based.

2. It should be distinctly national in character and should be a means of integrating and coordinating without controlling the activities of the various existing agencies of investigation. It should be so constituted that it may represent the United States officially in any international conference involving questions of nutrition.

3. It should be under the control of scientific men and not subject to the vagaries of legislative bodies nor dependent upon them for annual appropriations with the accompanying pressure to emphasize popular and spectacular work. This is an additional reason for not making it an executive department.

The natural organizing authority of such an institute as is here contemplated would seem to be the National Research Council. Both because of its intimate relations with the National Academy of Sciences and by virtue of the executive order of May 11, 1918, it is recognized as a national body representing the

organized scientific activities of the United States. Moreover, the Research Council has already taken a first step in the direction indicated by authorizing the appointment of a committee on food and nutrition. Presumably the purpose has been to select a committee representative of the nutrition investigators of the country while the matter is still sufficiently fluid to permit of any necessary modifications. Here, as it seems to me, is an ideal body to constitute a board of control of the proposed institute. It would determine, subject to the approval of the National Research Council, the general policy of the institute, while the immediate administration would naturally be confided to a director selected or nominated by the governing body and responsible to it but given large discretionary powers.

It would be premature to attempt to outline in any detail the field of work of a national institute of nutrition but it would seem that it would rather naturally divide itself into four sections:

I. *Statistical*.—What are the total food requirements of the United States? What is the actual food consumption and how much of this is avoidable waste? How is food consumption and food waste distributed among different classes of the population? What is our total food production, and can it be modified so as to secure more efficient utilization? Information on these and related questions should be kept up to date and available, using present statistical data so far as they suffice and collecting additional data if needed.

II. *Physiological*.—A scientific study of problems of human nutrition, such as those instanced by Lusk and others which might be added. The results of these investigations would afford the indispensable groundwork of the statistical studies just mentioned.

III. *Agricultural*.—A broad study of the economy of food production in the light of the food requirements of the nation and from the standpoint of the mutual interests of producer and con-

sumer. All the innumerable problems of plant and animal nutrition would find their place here, as well as broader questions regarding the relative economy of production of animal and vegetable foods and of different classes of each and of the most economical level of production under varying conditions.

IV. *Extension and Publicity.*—A very important function of the institute would be to bring the results of its work effectively to the attention of the community and of legislatures and executives, and to impress on them its vast economic and social importance.

It goes without saying that such an institute should cultivate most cordial relations with existing agencies. It should supplement, not supplant. If wisely and conservatively directed it might do much to bring about cooperation and coordination in the activities of extension departments, of nutrition laboratories, of experiment stations, and of the research and statistical divisions of the department of agriculture, so far as they relate to nutrition. Whether its objects could be sufficiently attained in this way or whether its policy should include in addition the establishment of laboratories of its own would be a question for the decision of the board of control.

Finally, as regards financial support, I believe that if as the result of free discussion and comparison of views a scheme can be worked out which has the approval of the scientific men of the country and which commends itself to the National Research Council as practicable and as promising material benefit to the public, past experience warrants the belief that the necessary funds will be forthcoming.

H. P. ARMSBY

THE MODERN SCIENCE OF FOOD VALUES

By HENRY PRENTISS ARMSBY

THE experiences of the great war have forced us to realize as never before that the maintenance of the food supply is the basal problem of civilization. Before commerce or manufacturing or mining can be carried on—before science or art or religion can flourish—man must be fed. A starving world cannot be made safe for democracy. Any rational programme of national or international preparedness, not only for possible future war but especially for the hoped for victories of peace, must have as its prime element the maintenance of an abundant food supply at prices which shall adequately reward the producer and not unduly tax the consumer.

That this is not only an urgent but an exceedingly complex problem is sufficiently evidenced by the current discussions in Congress and in the press and by the wide variety of proposals put forward for its solution. Just at present its economic and political aspects are those which chiefly occupy the public mind, but it must not be forgotten that nutrition is fundamentally a physiological question. Food must be abundantly produced and rationally consumed as well as honestly and economically distributed. Much attention has been given by scientists, especially during the last twenty-five years, to the physiology of nutrition, and notable progress has been made in the discovery and application of its basal laws. In these investigations, studies in the seemingly remote field of animal calorimetry have played a most significant part.

One of the most obvious features of the physical life of animals, including man, is the fact that they are continually producing and giving off heat. Indeed, death and the cessation of heat production are almost synonymous terms.

sumer. All the innumerable problems of plant and animal nutrition would find their place here, as well as broader questions regarding the relative economy of production of animal and vegetable foods and of different classes of each and of the most economical level of production under varying conditions.

IV. *Extension and Publicity.*—A very important function of the institute would be to bring the results of its work effectively to the attention of the community and of legislatures and executives, and to impress on them its vast economic and social importance.

It goes without saying that such an institute should cultivate most cordial relations with existing agencies. It should supplement, not supplant. If wisely and conservatively directed it might do much to bring about cooperation and coordination in the activities of extension departments, of nutrition laboratories, of experiment stations, and of the research and statistical divisions of the department of agriculture, so far as they relate to nutrition. Whether its objects could be sufficiently attained in this way or whether its policy should include in addition the establishment of laboratories of its own would be a question for the decision of the board of control.

Finally, as regards financial support, I believe that if as the result of free discussion and comparison of views a scheme can be worked out which has the approval of the scientific men of the country and which commends itself to the National Research Council as practicable and as promising material benefit to the public, past experience warrants the belief that the necessary funds will be forthcoming.

H. P. ARMSBY

THE MODERN SCIENCE OF FOOD VALUES

By HENRY PRENTISS ARMSBY

THE experiences of the great war have forced us to realize as never before that the maintenance of the food supply is the basal problem of civilization. Before commerce or manufacturing or mining can be carried on—before science or art or religion can flourish—man must be fed. A starving world cannot be made safe for democracy. Any rational programme of national or international preparedness, not only for possible future war but especially for the hoped for victories of peace, must have as its prime element the maintenance of an abundant food supply at prices which shall adequately reward the producer and not unduly tax the consumer.

That this is not only an urgent but an exceedingly complex problem is sufficiently evidenced by the current discussions in Congress and in the press and by the wide variety of proposals put forward for its solution. Just at present its economic and political aspects are those which chiefly occupy the public mind, but it must not be forgotten that nutrition is fundamentally a physiological question. Food must be abundantly produced and rationally consumed as well as honestly and economically distributed. Much attention has been given by scientists, especially during the last twenty-five years, to the physiology of nutrition, and notable progress has been made in the discovery and application of its basal laws. In these investigations, studies in the seemingly remote field of animal calorimetry have played a most significant part.

One of the most obvious features of the physical life of animals, including man, is the fact that they are continually producing and giving off heat. Indeed, death and the cessation of heat production are almost synonymous terms.

Reprint from THE YALE REVIEW, January, 1920.

Copyright by the YALE PUBLISHING ASSOCIATION, New Haven: Conn.

From the earliest times the animal heat was regarded as something innate and essentially vital, inexplicable by the ordinary laws of nature. Galen speaks of it as "that heat which is innate in the heart, which God placed there as the source of the heat of the body in the beginning of life and which remains there until death." That quantitative measurements of this animal heat should serve as a basis for the scientific nutrition of men and of animals and for the conservation and distribution of the food supply in a world war would have seemed wildly visionary even a hundred years ago, yet it is among the sober realities of the twentieth century.

The story dates back to Lavoisier, who demonstrated that respiration was substantially a process of slow combustion, and who gave what he regarded as satisfactory proof that this combustion was the source of the mysterious animal heat. Lavoisier's conception, however, was too bold to find immediate acceptance, and the experimental methods available to his successors were inadequate for its investigation. It was not until 1894 that Rubner, with improved technique, was able to furnish a satisfactory demonstration of the correctness of Lavoisier's conclusion. In the average of seven experiments on dogs, covering in all forty-five days, he found a difference of less than one-third of one per cent between the computed heat production and that actually measured by his calorimeter.

Some remaining sources of uncertainty in Rubner's work were subsequently eliminated in very rigorous experiments, by Atwater and his associates, upon men. Thirty experiments by these investigators published up to the end of 1903, extending over ninety-three days and involving nearly a quarter of a million calories of heat, showed an average difference of only .05 per cent. Later experiments by Benedict and his co-workers with an improved form of apparatus showed a difference of about 1,100 calories in a total of almost 200,000, or .57 per cent. A summary made

a few years ago of all the results on different species then available, covering a total experimental period of 374 days and an aggregate heat production of over 1,800,000 calories, showed an average difference of .21 per cent.

But we miss the full significance of investigations in animal calorimetry if we think of them simply as experiments on the source of animal heat. Their scope is much broader. They demonstrate that the law of the conservation of energy obtains in the animal as elsewhere and thus lead to the conception of the body as a mechanism for the utilization of energy supplied to it in its food. Moreover, since none of this energy is destroyed, they show that it is possible to measure the efficiency of the animal mechanism by comparing its energy income with the various forms of energy outgo.

But while animal calorimetry has thus made an important contribution to our knowledge of the working of the animal body, it is pertinent to inquire what direct service has been rendered to mankind by these laborious and costly investigations. While it is a narrow and barren ideal which demands that each piece of scientific research justify itself by some material outcome, the pursuit of "knowledge for its own sake" is an equally extreme and unfruitful conception. In the broad view, knowledge is valuable not for itself but for its effects, including, of course, its effect upon the mind which perceives it. Animal calorimetry need not fear this test. While less than a quarter of a century has elapsed since Rubner initiated the modern study of the subject, it has already proved fruitful of results and is steadily opening up new paths for investigation.

Clinical medicine, for example, is coming to profit largely by the results of comparative calorimetric observations on healthy and diseased individuals. Forms of portable respiration apparatus like those of Zuntz or Benedict render such observations at the patient's bedside a comparatively simple matter, while more elaborate studies with fixed

apparatus of the chamber type are being successfully used, notably at the Nutrition Laboratory of the Carnegie Institution, under the direction of Benedict, and at Bellevue Hospital, New York, by Du Bois on the initiative of Lusk.

Comparisons of this sort give a far more definite picture of the effects of disease and of treatment than can be obtained in any other way. Thus, in goitre, it has been found that the body combustions are stimulated strictly in proportion to the severity of the disease, so that the heat production may serve as a clinical index to the results of surgical or medical treatment or to the effects of the diet. Diabetes is another disease whose nature is being extensively studied calorimetrically, and although no specific remedy has yet been discovered, important information regarding the effects of proposed methods of treatment such as the so-called "oatmeal" and "fasting" methods has been obtained.

Some most interesting results upon typhoid fever have been reported. In the first place, it has been shown that the high body temperature in this disease is due to a greater production of heat and not to a failure to eliminate heat from the body at a normal rate. It follows from this that the body of the patient is burning up more material than normally and, following up this hint, the so-called "high-calorie" diet, supplying especially liberal amounts of carbohydrates, has been found of marked benefit. Moreover, it has been shown that such diet does not, in the typhoid patient, have the effect in stimulating the body combustions which is observed in the healthy individual. Du Bois writes: "The practical application of all this is that typhoid patients need more food than normal men under similar conditions and that food in quite large amounts is well absorbed and does not increase heat production, as was previously feared." Moreover, it has been shown that very liberal feeding, especially with carbohydrates, may reduce or prevent the wasting away of the muscles and other tissues which otherwise takes place.

It is perhaps in the field of nutrition, both human and animal, that results of the most general interest have been reached. If the energy expended by the animal originates in a combustion in the body, it is clear that the substances burned must be derived directly or indirectly from the food, since otherwise the body itself would soon be consumed. The food is obviously the fuel of the animal mechanism. The primary purpose of this mechanism is the performance of mechanical work. It moves itself from place to place, gathers or captures its food, and in case of man and domesticated animals performs a variety of useful labor. At the same time it produces a large amount of heat, some of which is of use in keeping it warm, but this is substantially an incident and not an end of the body combustion.

A fairly close analogy may be drawn between the body and an internal combustion motor. In both a fuel—food in the body, gas or other combustible material in the motor—is burned, producing primarily motion and secondarily heat. Both the body and the motor are transformers of energy. In each, the chemical energy of fuel is converted in part into mechanical work while the remainder escapes as heat. Accordingly, students of nutrition have come to regard the food as primarily a source of energy for the body mechanism and to look upon the variety of other functions which the food ingredients perform, however essential, as tributary to this main end. The general acceptance of this point of view is due largely to the calorimetical investigations of Rubner and others already mentioned. They showed not only that the combustions in the body are the sole source of the animal heat but that the principal ingredients of the food—proteins, carbohydrates, fats—may be substituted for each other, within wide limits, in proportion to the amounts of energy which they are capable of supplying to the body.

The first practical application of the idea that food values could be expressed in terms of energy was in the field of

human nutrition, the pioneers being Rubner in Germany and Atwater and his associates in the United States. Thanks to their labors and to those of a host of their successors and pupils, the conception has become common property. The popular magazine contributor writes glibly of energy values, and the up-to-date housewife "riseth early while it is yet night" and giveth calories unto her household.

Most can raise the flower now
For all have got the seed.

Studies of the food requirements of man as expressed in his heat production under ordinary conditions have been especially numerous. That muscular activity is a potent factor in the food requirement is well known from experience, but experiments in which various occupations have been carried on in the chamber of a calorimeter or in which the heat production has been measured by the indirect method have given quantitative value to the facts of common knowledge. The influence of bodily position, too, has proved to be a not insignificant factor. A woman required to stand ten or twelve hours a day behind the counter of a store, to say nothing of other ill effects, consumes some 16½ per cent more body tissue than when sitting quietly in a chair. Lying on a couch completely relaxed reduces the heat production in the body by from 5 to 10 per cent as compared with sitting upright, while, curiously enough, lying propped up comfortably in a steamer chair has recently been found to reduce it still further, so that there is a certain physiological justification for the favorite attitude of the lazy man with his chair tilted back and his feet on the desk. The influence of other factors, such as sex, age, and athleticism, has likewise been investigated, and for many occupations it is now possible to compute with a good degree of accuracy the average daily requirement of a man or woman on the basis of the number of hours spent sleeping, sitting quietly, walking about, and working at a specific vocation.

Parallel with these investigations upon energy requirements have gone determinations of the quantities of energy available in foods; and extensive tables have been prepared which render it a simple task to compute a dietary supplying the required amount of energy.

The significance of such data as these for the nutrition of the individual is obvious. While by no means the sole factors to be considered, the energy values of foods constitute the readiest and simplest means of comparison between prices and total nutritive values. Together with a rational selection as between different classes of foods and reasonable skill in their preparation, they afford the possibility of combining economy in the household account with notable improvement in nutrition, particularly for people of limited means, and so of a corresponding increase in productive capacity both physical and mental. When it is considered that not less than 25 per cent of the average income is spent for food the economic importance of the matter to the individual and to the community becomes obvious. Especially where large numbers of men have to be fed, as in prisons, asylums, military and labor camps, energy values afford a great aid in combining efficiency with economy in nutrition. A notable example of success in this field is found in the work of the Sanitary Corps of the Surgeon General's Office in our army camps.

Energy data also afford the most adequate measure of the food requirements and food supply of a nation. Perhaps the most striking instance of the wide scope for the application of these fundamental principles of nutrition was found in the field of international food supply during the war. The diversion of millions of men from agricultural production to military service, and the havoc incident to war, together with the deficiency of shipping due to transport demands and the submarine menace, resulted in a threatening shortage of food. This shortage compelled not only a stimulation of production to the greatest practicable

extent but likewise the exercise of the utmost economy on an international scale, particularly by the European nations. Recognizing that the determination of the food resources and needs of each country was essentially a physiological problem, the Inter-Allied Conference held in Paris in November, 1917, provided for the creation of the organization known as the Commission Scientifique Interalliée du Ravitaillement, to be composed of scientific experts delegated by the governments of France, Great Britain, Italy, Belgium, and the United States. The task of the Commission was to study from a scientific point of view questions of food control—especially the problem of the equitable allocation of the available food supply among the Allied nations, and to make recommendations to their governments.

The Commission entered promptly upon its work and was actively engaged on it for two and one-half months in the spring and summer of 1918, holding formal sessions in Paris, Rome, and London, a prominent part in the proceedings being taken by the American delegates, Chittenden and Lusk. It was agreed by this Commission that energy values afforded the best unit of comparison; and by thus reducing the available data for consumption and production to a common denominator it was found possible to formulate a programme for the equitable allocation of food importations among the European nations, taking account of their population, average food requirement per individual, and probable domestic production. The programme thus recommended was partially carried out. The Commission was called together for the second time in the fall of 1918, but the unexpected signing of the armistice radically changed the situation, setting free more or less overseas tonnage, and introducing the problem of the food needs of the occupied regions. These changes, together with difficulties in internal transportation, rendered it impracticable to make definite recommendations. Although the early conclusion of the war cut the work short, even the formula-

tion of a food programme, based upon scientific studies of nutrition, was a notable achievement and a striking instance of the practical value of calorimetric studies of nutrition.

The energy requirements of domestic animals, and the energy values of the feeding stuffs which they consume, have also been the subject of extensive investigations, including especially those by Zuntz and his associates at Berlin on the horse, by Kellner and his colleagues at Moeckern on cattle, by Tangl in Budapest and Fingerling at Moeckern on swine, and by the writer and his associates on cattle, as well as the great mass of feeding experiments of more or less elaborate nature conducted by the agricultural experiment stations in this and other countries. As in the case of man, fairly satisfactory data have been accumulated regarding the energy content of stock feeds and the energy requirements of different species of farm animals, both for simple maintenance and for various forms of production, more especially of meat, although much further investigation is greatly needed.

That such data are capable of rendering important aid to the feeder of live stock is sufficiently evident, but their wider economic significance is perhaps not so obvious. For a full understanding of the latter it is necessary to consider briefly the part played by animals in the production of human food.

The crude products of the farm are not human food. This is obviously true of products like the hay and straw necessarily incident to the production of food crops, but even grains such as wheat and corn, although commonly thought of as directly available to man are so only in part. Man does not eat wheat, but wheat flour or its products, and a bushel of wheat yields ordinarily only about $43\frac{1}{2}$ pounds of white flour along with $16\frac{1}{2}$ pounds of mill offals useful only as stock feed. The function of the food animal is that of a converter. It changes the vegetable products

of the farm or ranch into the highly palatable meat or the milk which is of such importance especially in the nutrition of infants and growing children. In accomplishing this, it transforms the vegetable proteins of the feed into the more valuable animal proteins, a due supply of which is highly important in nutrition, and a comparatively small amount of which has been shown to enhance greatly the value of vegetable proteins consumed with them. Finally, and most important, the animal is able to manufacture these products to a considerable extent from materials which are of little or no direct food value to man because inedible by him. Such are, for example, roughages like hay, corn-fodder, straw, and the like, and the by-products of technical operations such as bran and oil meals. To the extent to which the animal can accomplish this transformation, the milk or meat produced constitutes a direct addition to the total food supply.

The fundamental studies in animal nutrition, to which reference has been made, are concerned primarily with the efficiency of this transformation. They seek to ascertain what proportion of the stored-up solar energy contained in stock feeds can be recovered in the meat or milk produced and utilized to operate the human machine. Three general lines of investigation are being pursued. First, the energy content of different feeding stuffs and the proportion of it which can be utilized by animals is being studied. Second, the efficiency of the animal as a transformer is being investigated, and we are learning how the beef steer, the pig, and the dairy cow compare in this respect, or how the pure bred differs from the scrub animal, the nervous from the phlegmatic one, or the fat from the thin one. Third, the influence of external factors such as temperature, shelter, and quiet upon feeding economy is being investigated.

In general terms, the experimental method employed both with men and animals consists of a comparison of income

and outgo of energy. The income is represented by the heat of combustion of the food, just as that of an engine is measured by the heat of combustion of its fuel. The outgo of energy in the unburned materials of the visible excreta is determined in the same way, and the measurement of any external work performed is not especially difficult. The measurement of the large amount of energy dissipated as heat, on the contrary, requires a complicated and costly apparatus known as a "respiration calorimeter." Numerous forms of this instrument have been constructed, but the type in most general use is that devised by Atwater and Rosa, in which the subject is placed in a closed chamber from which the products of respiration are removed by a ventilating air current and determined, while the heat produced, prevented by ingenious electrically controlled compensating devices from escaping through the walls of the chamber or in the ventilating air current, is taken up as fast as given off by a current of cold water, the rise in temperature of which is measured. The general principle of the apparatus is readily comprehended, but the elaborate appliances and precautions required to secure accurate results render such experimentation both expensive and time-consuming.

The bearing of experiments of this sort upon questions of nutrition and food supply may be conveniently illustrated by the averages of a considerable number of experiments on beef cattle, showing the partition of the stream of energy entering the body in the feed. It was found that of the total energy in ordinary roughages such as hay, straw, corn-fodder, and the like, approximately 57 per cent is rejected unused in the visible excreta, and about 23 per cent more is expended in the increased heat production which is always found to result from the consumption of feed, so that only about one-fifth of the amount supplied to the animal is actually stored up as increase of flesh or fat. In average grain feeds the loss in the excreta is much smaller, about 33

per cent, and the increase in heat production somewhat greater, about 27 per cent, so that approximately 40 per cent of their energy is recovered. It is apparent from these results that beef production is a rather expensive process, involving relatively large losses of energy both from roughages and concentrates. Individual feeding stuffs show an even wider range, the maximum utilization noted in these experiments for a grain being 46 per cent for corn meal, and the minimum for a roughage being 13 per cent for oat straw, while as low a figure as 5 per cent has been observed in the case of wheat straw. In milk production the losses are probably somewhat less and in pork production distinctly so, yet at best only a rather small percentage is actually recovered. From this point of view it also appears that average grain is about twice as available as average roughage.

But these figures do not tell the whole story. In the first place, not all of the 20 to 40 per cent of the feed energy which is stored up in body increase or in milk is actually available to man. A thousand pound steer yields only about 580 pounds of carcass and of this practically 100 pounds is inedible waste, while there is further loss due to the fact that the meat is not wholly digestible by man. Only about 43 per cent of the total feed energy retained in the body of the steer is actually utilized for human nutrition. The sheep makes a somewhat better showing, yielding about 49 per cent. With pigs and dairy cows, on the other hand, from 90 to 95 per cent of the feed energy stored up is available for man's support.

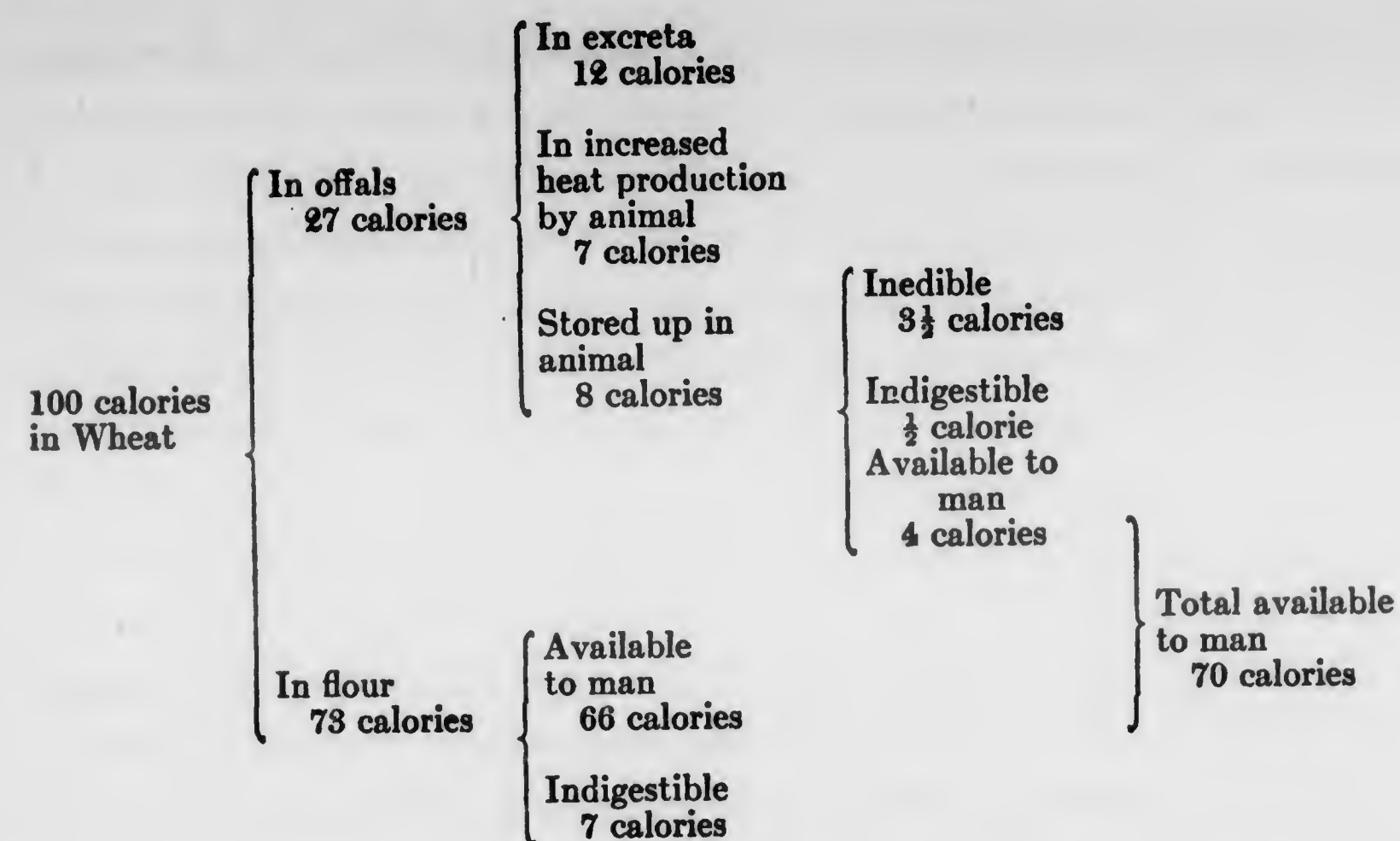
Still further, it has to be borne in mind that a certain amount of the available energy supplied to the animal in its feed is required for the operation of the bodily machinery, constituting the so-called maintenance requirement, or overhead feeding cost, which must be provided for before any production at all is possible.

It is obvious from all this that while the animal per-

forms an important function in the utilization of food values which would otherwise be wasted, nevertheless the use by animals of *potential human food* results in a great loss of energy. Thus when corn is converted into beef or pork, a large amount of human food is sacrificed, partly for the sake of securing better forms of protein, partly for the sake of the resulting fat, but to a large degree for the sake of the more attractive flavor of meat.

Studies of the energy values of feeding stuffs afford a basis for computing the extent of this sacrifice as well as for determining how farm products may contribute most efficiently to the nutrition of the community. For example, a bushel of average wheat contains about 110,000 calories of total energy. How much of this can be recovered for human nutrition? In general, it may be stated that it is readily possible to cover the food cost of maintenance of farm animals by the use of cheap roughages or of materials unavailable for human food. Assuming that this is done, and that the wheat is used only as the productive part of a ration, it is possible on the basis of experiments like those just described to compute how much of the energy of the wheat can be recovered in edible form when fed directly and how much when it is converted into flour for human use and the by-products fed to live stock.

Taking beef production as an illustration, it is found that when wheat is fed directly to a beef steer each hundred calories of energy in the wheat is distributed as follows, only 22 per cent being finally utilized: in excreta, 25 calories; in increased heat production by the animal, 25 calories; stored up in the animal, 50 calories. Of the total amount stored up 25 calories are inedible; 3 calories, indigestible; and 22 calories available to man. If, on the other hand, the wheat be milled and the flour used for human food, only the milling offals being utilized in beef production, about 70 per cent is recovered as may be seen from the following analysis:



Computations have been made for other grains and for other species of animals, from which it appears that when they are fed directly to cattle or sheep from 15 to 24 per cent of the energy consumed is rendered available as human food, while if the grains are milled and only the milling offals fed to animals, from 56 to 81 per cent can be recovered. When fed directly to pigs or dairy cows, the recovery ranges from 36 to 61 per cent, while milling the grains and feeding the offals give a percentage recovery of 60 to 85 per cent. These comparisons serve to illustrate the way in which the animal can aid in the conservation of food energy and likewise the fact that economy requires that the largest proportion possible of the food grains be consumed directly by man and only the remaining residues used for stock feeds. Other methods of utilization, such as the higher percentage milling of wheat or the production of "whole wheat" flour, the manufacture of hominy or of starch and glucose from corn, or the use of grains in brewing and distilling, may be compared in the same general way. In the latter case, for example, the percentage recovery of energy may be computed to be approximately 28 to 35 per cent in brewing, and 5 to 13 per cent in distilling, if the alcohol be not included; while assum-

ing for the latter its theoretical food value (a questionable assumption) the figures would be raised from 28 to 53 per cent in brewing and 59 to 67 per cent in distilling. It is apparent that, even on the most favorable assumption, the recovery of energy for man's use in brewing or distilling is much less than that obtained by milling the same materials.

The foregoing comparisons likewise illustrate the differences between different species of animals as conservers of food energy. The beef steer and the mutton sheep show a relatively low efficiency as meat producers as compared with the pig, provided, as is here assumed, that the maintenance requirement of the latter is satisfied by forage crops or by inedible by-product feeds. On the other hand, if the pig is fed largely on grain, as has been common in the past, he becomes a direct competitor of man. Finally, the dairy cow shows the highest efficiency of any domestic animal, both as regards conversion of feed into milk and the availability of the product for man. This is a fact of the greatest significance in national nutrition. Taken in connection with the indispensability of milk in the diet of infants and young children and its high value in the diet of all classes, it is obvious that all possible encouragement should be given to maintaining an abundant milk supply and to promoting the dairy industry in general.

Nutritional physiology offers no panacea for the high cost of living. It holds forth no hopes of revolutionary discoveries which shall make one loaf of bread serve where two served before. It cannot abrogate economic laws. Its task is the humble and prosaic yet indispensable one of learning by patient research how the food producing agencies of the nation may most efficiently serve the whole people and how the products of their activity may be used with the minimum of waste by preventing improper or unskilful selection and combination.

Heretofore the United States has literally had "food to burn"—sometimes actually as fuel, oftener in the bodies of

domestic animals. Those days are gone never to return. Even though we may hope to make an end of war we cannot hope to escape from the world's continually growing demand for food. The density of population that can be supported is practically limited by the amount of solar energy which the farmer can recover in food products and the efficiency with which these products can be utilized as fuel for the human body. Any rational effort to extend this limit must include as its prime requirements not only a systematic development of agricultural production such as is now being effected by national and state agencies but also an equally systematic attention to the conservation and most efficient utilization of the products of the farm. The two are but different aspects of the one great problem of national nutrition. Without reflecting upon any existing agencies, surely it is high time that, along with military, naval, transportation, and manufacturing programmes, this fundamental problem, vital to our national existence and welfare, should be taken up in its entirety by some national agency charged with the investigation of the scientific and economic aspects of food supply and utilization, and with the diffusion of the knowledge, thus gained, among the people.

Reprinted from the Proceedings of the NATIONAL ACADEMY OF SCIENCES,
Vol. 6, No. 5, pp. 263-265, May, 1920

THE CARBON DIOXIDE: HEAT RATIO IN CATTLE

BY HENRY PRENTISS ARMSBY, J. AUGUST FRIES AND WINFRED
WAITE BRAMAN

INSTITUTE OF ANIMAL NUTRITION, THE PENNSYLVANIA STATE COLLEGE

Communicated by F. G. Benedict, March 24, 1920

It was recently suggested to us by Dr. F. G. Benedict that if the ratio of the carbon dioxide excreted to the heat produced by cattle should prove to be sufficiently constant, this fact might be utilized as the basis for determinations of the energy metabolism of this species which would be approximately correct and which would require only a comparatively simple technique. In view of the great value which such a simplified method would have, especially for agricultural investigators, and of the further fact that a new form of respiration apparatus designed to be used in this manner has been constructed by Benedict in coöperation with the New Hampshire Agricultural Experiment Station, we have thought it worth while to study the results of our calorimetric experiments on cattle from this point of view and we present the results of that study herewith.¹

These experiments were made with the Atwater-Rosa respiration calorimeter which has been in use here since 1901, the heat production as well as the elimination of carbon dioxide being measured, and are, so far as we are aware, the only direct determinations of the heat production of this species. The measured heat production has been compared with the carbon dioxide elimination in 188 24-hour periods.² The carbon dioxide included, of course, the considerable amount arising from the methane fermentation in the rumen. The following results were obtained for the heat expressed in kilogram calories divided by the carbon dioxide expressed in grams.

CARBON DIOXIDE : HEAT RATIO OF CATTLE

Range.....	2.1500 to 3.1500
Mean value.....	2.4947 $\pm$ 0.0085
Standard deviation.....	0.1713 $\pm$ 0.0060
Median.....	2.4938
Theoretical mode.....	2.4974
Error of single variate.....	$\pm$ 0.12
Coefficient of variability.....	6.87%

In 51 of these periods we have also data for the carbon dioxide and heat production of the animals in the standing and lying positions respec-

tively. A comparison of these shows a somewhat smaller ratio in the lying than in the standing position.

CARBON DIOXIDE : HEAT RATIO OF CATTLE

	STANDING	LYING
Range.....	1.8600 to 2.9400	1.6900 to 2.5700
Mean value.....	2.5129 $\pm$ 0.0185	2.2529 $\pm$ 0.0149
Standard deviation.....	0.196 $\pm$ 0.013	0.158 $\pm$ 0.011
Median.....	2.5020	2.2713
Theoretical mode.....	2.4802	2.3081
Error of single variate.....	$\pm$ 0.13	$\pm$ 0.11
Coefficient of variability.....	7.80%	7.01%

A further study of the results indicated that the rather wide range in the single values of the CO₂ : heat ratio was caused in large degree by variations in the amount of feed consumed, the ratio tending to decrease as the amount of feed increased. This is what would have been expected for two reasons. First, the CO₂ : heat ratio for the methane fermentation, although not very satisfactorily determined, is undoubtedly much lower than that due to the tissue metabolism of the animal and as the feed is increased this constitutes an increasing proportion of the total elimination. Second, it is clear that the formation of fat from carbohydrates which takes place on a heavy ration would tend to lower the ratio; while, on the other hand, the oxidation of body fat on an insufficient ration would tend to increase the ratio. It should be noted also that our subjects were performing no external work and while not absolutely at rest were for the most part standing or lying quietly. Any considerable muscular exertion would doubtless have materially increased the ratio.

In 99 48-hour experiments, the factor of the varying size of the subjects being eliminated by computing all the results per kilogram of live weight, it appeared from a graph in which the abscissas represented the total weights of feed consumed and the ordinates, respectively, the grams of carbon dioxide excreted, the calories of heat measured and the ratio Heat/CO₂, that the individual results grouped themselves quite closely about three straight lines which could be represented by the three following linear equations, in which

x = Air-dry weight of feed in grams per kilogram of live weight

y_1 = Calories of measured heat per kilogram live weight

y_2 = Grams of CO₂ per kilogram live weight

$$y_3 = \frac{\text{Heat}}{\text{CO}_2} = \frac{y_1}{y_2}$$

$$(1) y_1 = 0.869x + 14.176$$

$$(2) y_2 = 0.455x + 4.365$$

$$(3) y_3 = -0.0226x + 2.802.$$

A computation of the closeness of fit of the lines represented by the foregoing equations to the individual results gives the following values for the index (Δ) and the probability (P).

$$\begin{aligned}\Delta_1 &= 4.489 \\ \Delta_2 &= 2.467 \\ \Delta_3 &= 0.663\end{aligned}$$

$$\begin{aligned}P_1 &= 0.9508 \\ P_2 &= 0.9640 \\ P_3 &= 0.9986\end{aligned}$$

It would perhaps have been preferable to make the comparisons with the dry matter of the feed consumed. No succulent feeds, however, were contained in the rations and it does not seem probable that the slight differences in moisture content can have materially affected the conclusions. We have not attempted to distinguish between the effects of different kinds or classes of feeding stuffs and doubt whether our data are sufficiently extensive to warrant it.

It would appear from the foregoing data that within the range of these experiments, i. e., with feed varying from 5 to 27 grams per kilogram live weight, equation (3) may be used for computing the CO₂ : heat ratio of cattle when their live weight and the amount of feed consumed are known, and that by the use of this ratio the heat production may be computed from the observed CO₂ production with a good degree of accuracy, at least for animals on dry feed and not performing work.

It should be noted, however, that the values of y_3 computed from equation (3) differ slightly from the ratios computed from the corresponding values of y_1 and y_2 , indicating that y_3 is not a strictly linear function of x . The discrepancy does not appear sufficient to affect materially the computation of the heat production from the CO₂ on the amounts of feed used in these experiments but for the fasting animal, i. e., when $x = 0$, the discrepancy is much more considerable, viz.:

$$\frac{y_1}{y_2} = 3.25 \quad y_3 = 2.80$$

It appears probable that the values of y_3 would be represented more exactly by a line slightly convex toward the horizontal axis and curving somewhat more sharply upward as the value of x approaches zero, and that for very small amounts of feed the CO₂ : heat ratio computed from the values of y_1 and y_2 is more accurate than that computed from equation (3). This conclusion is strengthened by the fact that the fasting value thus obtained approximates quite closely that observed by Benedict in his experiments on fasting men.

¹ The entire credit for the mathematical discussion of the results as well as for the laborious computations involved is due to Mr. Braman.

² In most instances two of these periods constituted the two halves of one of the 48-hour experiments mentioned subsequently.

OBSERVATIONS ON THE BODY TEMPERATURE OF DRY COWS

By MAX KRISS¹

Associate in Animal Nutrition, Institute of Animal Nutrition, The Pennsylvania State College

COOPERATIVE INVESTIGATIONS BETWEEN THE INSTITUTE OF ANIMAL NUTRITION OF THE PENNSYLVANIA STATE COLLEGE AND THE BUREAU OF ANIMAL INDUSTRY OF THE UNITED STATES DEPARTMENT OF AGRICULTURE

The normal temperature of the animal body is never a constant figure. It varies in different species, in different individuals, and is never absolutely constant even in the same individual. The observations on the body temperature of man are numerous and more or less conclusive, while relatively little attention seems to have been given to the study of the variations in the body temperature of farm animals under different conditions which are known to affect the temperature of man.²

In healthy warm-blooded animals, notably cattle, as well as man, the body temperature fluctuates within very narrow limits. When, however, the normal processes of the body are upset, the temperature may vary widely, and for this reason body temperature is looked upon as an index of health. But aside from this and from any other physiological significance that it might have, knowledge of the normal course of fluctuations in body temperature of cattle has grown in importance with the perfection of the respiration calorimeter used in the investigations on metabolism with cattle.

By means of the respiration calorimeter the heat produced by the animal during a certain period of time, as well as the gaseous exchange between the animal and the atmosphere that surrounds it, is measured. But in order to determine accurately the heat production as distinguished from the heat emission, a knowledge of the storage or loss of heat by the animal body is indispensable. If at the end of an experimental period

¹ I am under obligation to Dr. H. P. Armsby for the opportunity to carry out this investigation, and I wish to thank him for his invaluable suggestions and kindly criticism. I also wish to thank the other members of the staff, especially Prof. J. A. Fries and Prof. W. W. Braman for the interest they have shown and for the suggestions they have given me.

² PEMBREY, M. S. ANIMAL HEAT. In Schäfer, E. A., ed. Text-Book of Physiology. p. 785-867, fig. 76-82. Edinburgh, London, New York, 1898.

the body temperature of an animal weighing 400 kgm. is 1° C. higher or lower than that at the beginning, it would mean, in the first case, a storage and, in the second case, a loss of heat by the body amounting to 332 calories (assuming the specific heat of the body to be 0.83). Such a quantity would be too large to be entirely ignored in accurate determinations of heat production.

It has been generally claimed that in 24- or 48-hour respiration calorimeter experiments no serious error is introduced by the assumption that the body temperature is approximately the same at approximately the same hour of the day. It was the main purpose of this experiment to obtain data regarding the extent and the course of the body temperature variations in cattle and to study some of the factors that might influence them. With this object in view, observations on the body temperature of cows have been made with reference to the study of the following:

1. Variations in body temperature from about 7.30 a. m. to about 5.30 p. m., including the effect of water drunk.
2. Thermal gradient in the body.
3. Variations in body temperature from about 5 p. m. to about 7 p. m., including the effect of the feed.
4. Effect of the act of defecation and of change in position.
5. Daily variations in temperature measured at exactly the same time of the day.

SUBJECT AND CONDITIONS OF THE EXPERIMENT

It is essential, in order to get comparable results, that the temperature observations on the subject be made under as strictly uniform conditions as practicable. This condition of the experiment fortunately existed to great satisfaction, since the animals used for this experiment were those used at the same time at the Institute of Animal Nutrition for metabolism experiments with the respiration calorimeter, in which strict control of feeding, environment, etc., is maintained. It may perhaps not be superfluous to give a complete description of the animals used for this experiment in order that a fuller appreciation of the individual variations in body temperature may be later had in considering the experimental results.

DESCRIPTION OF THE ANIMALS

The animals used were two dry cows, No. 885 and No. 886. They are both pure-bred registered Jerseys. Cow 885 was born on March 27, 1914, and dropped her first and last calf on September 15, 1917. Cow 886 was born on July 13, 1914, and dropped her first and last calf on October 10, 1917. They weigh about 400 kgm. each and resemble each other very much in respect to both size and color.

Both cows were in good health throughout the experiment.

LOCATION

The cows were located during the experiment in the institute barn, which is a closed wooden building provided with a coal stove so that the temperature of the room could be kept fairly uniform.

TIME AND RATIONS

The investigation covers a period of some 16 weeks from December 1, 1919, to March 22, 1920. The cows were kept on a maintenance ration, except that from December 20, 1919, to January 24, 1920, cow 886 received a supermaintenance ration, and from January 10 to February 7, 1920, cow 885 received a supermaintenance ration, about 1.5 times the maintenance ration in both cases.

FEEDING AND WATERING

The cows were fed twice during every 24 hours, at 6 a. m. and at 5 p. m., unless the time was changed for experimental purposes, in which case it has been specified. They were watered only once a day, at about 8 a. m., the amount of water drunk and the temperature of the water being recorded.

BARN TEMPERATURE

A continuous record of the temperature of the barn was obtained by means of the Columbia recording thermometer. But besides this the temperature of the barn, as indicated by a mercurial thermometer, was recorded simultaneously with every observation on the body temperature of the animal.

METHOD OF MAKING BODY-TEMPERATURE OBSERVATIONS

The observations on the body temperature were made by means of carefully standardized clinical thermometers. During the greater part of the experiment one and the same thermometer was used, while for simultaneous readings of the rectal and vaginal temperatures a second one was used. To avoid any possible error as to the relative value of the rectal and vaginal temperatures that might be due to the use of two different thermometers, the latter were for a few days interchanged—that is, the thermometer used one day for measuring the rectal temperature was used the following day for the vaginal, and vice versa. This was further checked by using one and the same thermometer for both the rectal and vaginal temperature readings, taken one immediately after the other.

All observations except those on the thermal gradient were made at a depth of 7 inches. The thermometers, which were originally 5 inches long, were accordingly lengthened by means of a piece of rubber tubing slipped $\frac{1}{2}$ inch or so over the upper end of the thermometer and the

remaining portion over the string attached to the loop of the thermometer and stiffened by inserting inside the rubber tubing a strip of copper wire. This was finally covered with adhesive plaster and a rubber ring tightly fitted at the end. This arrangement proved very satisfactory. In the first place, the thermometer could be inserted to the desired depth, and, in the second place, there was little danger of breaking it during the insertion.

The thermometer was ordinarily allowed to stay in the rectum or vagina for about three minutes, and the time and temperature were recorded immediately upon its removal.

EXPERIMENTAL RESULTS

The results are expressed in the form of curves. In all curves except those of the thermal gradient the hours or dates are expressed by horizontal distances, and the corresponding temperatures are represented vertically. In the curves of the thermal gradient the horizontal dis-

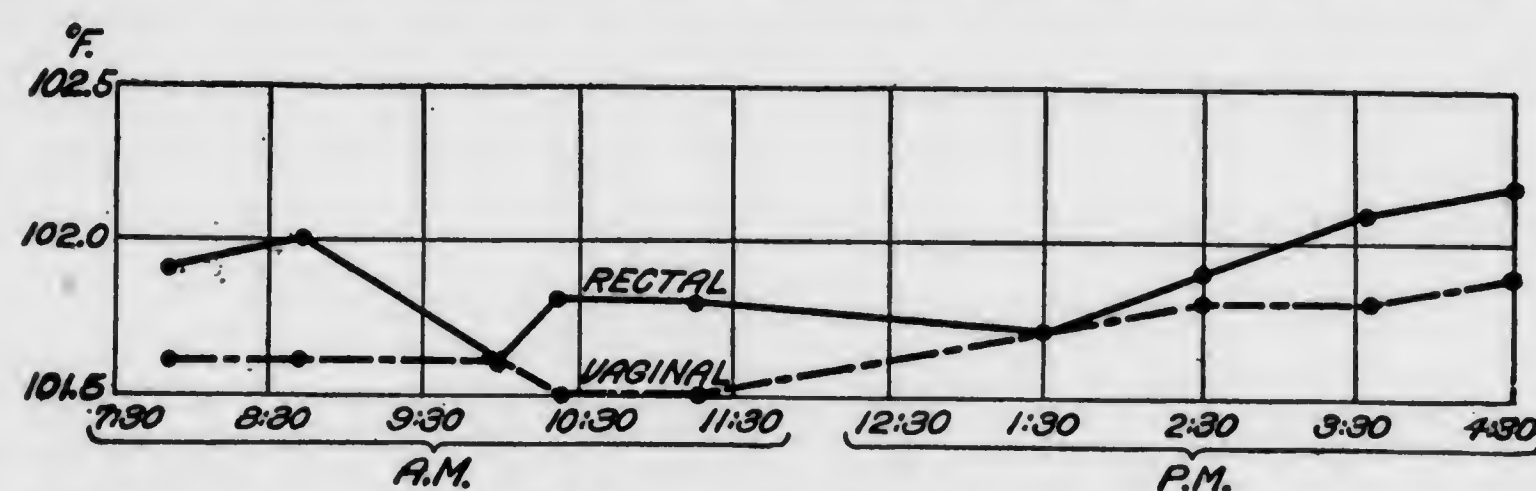


FIG. 1.—Variations in body temperature of cow 886 on December 1, 1919, 7.50 a. m. to 4.30 p. m.; 7.50 a. m. immediately after urinating; 8.25 a. m. drank 5.2 kgm. of water at 52° F.; 10 a. m. lying; 10.22 a. m. standing and immediately after defecating; 11.15 a. m. lying; 1.30 p. m. lying; 2.30 to 4.30 p. m. standing; 3.32 p. m. immediately after defecating.

tances represent the depths of insertion, and the vertical distances represent the corresponding temperatures.

The barn temperatures are not given because they were too uniform to have had any appreciable effect on the body temperature, ranging in most cases between 50° to 60° F.

To facilitate comparisons, the different types of curves for the two cows have been arranged to follow each other in more or less chronological order.

VARIATIONS IN BODY TEMPERATURE FROM ABOUT 7.30 A. M. TO ABOUT 5.30 P. M.

OBSERVATIONS ON DECEMBER 1, 1919, WITH COW 886

Readings of the rectal and vaginal temperatures were taken at approximately 1-hour intervals from 7.50 a. m. to 11.15 a. m. and from 1.30 p. m. to 4.30 p. m. The vaginal temperature was measured immediately after the rectal by the same thermometer. The reading of the vaginal temperature at 7.50 a. m. was taken immediately after the cow had

urinated. At 8.25 a. m. the cow drank 5.2 kgm. of water at 52° F. During the observations at 10 a. m., 11.15 a. m., and 1.30 p. m. the cow was lying; during all others she was standing. The readings at 10.22 a. m. and 3.32 p. m. were taken immediately after the animal had defecated. The results of these observations are shown in figure 1.

The curve for the rectum shows a slight fall in temperature between 8.40 a. m. and 10 a. m., the period following the drinking of the water. It then slightly rises and from 10.22 a. m. to 1.30 p. m. forms almost a straight line. From 1.30 p. m. to 4.30 p. m. it shows a gradual rise of temperature.

The curve for the vagina is in general lower than that for the rectum. It does not show, however, any effect of the water drunk, forming a straight line till 10 a. m. and meeting the rectal curve at that time. The two curves then diverge to meet again at 1.30 p. m. They then diverge again but soon run almost parallel to each other till 4.30 p. m.

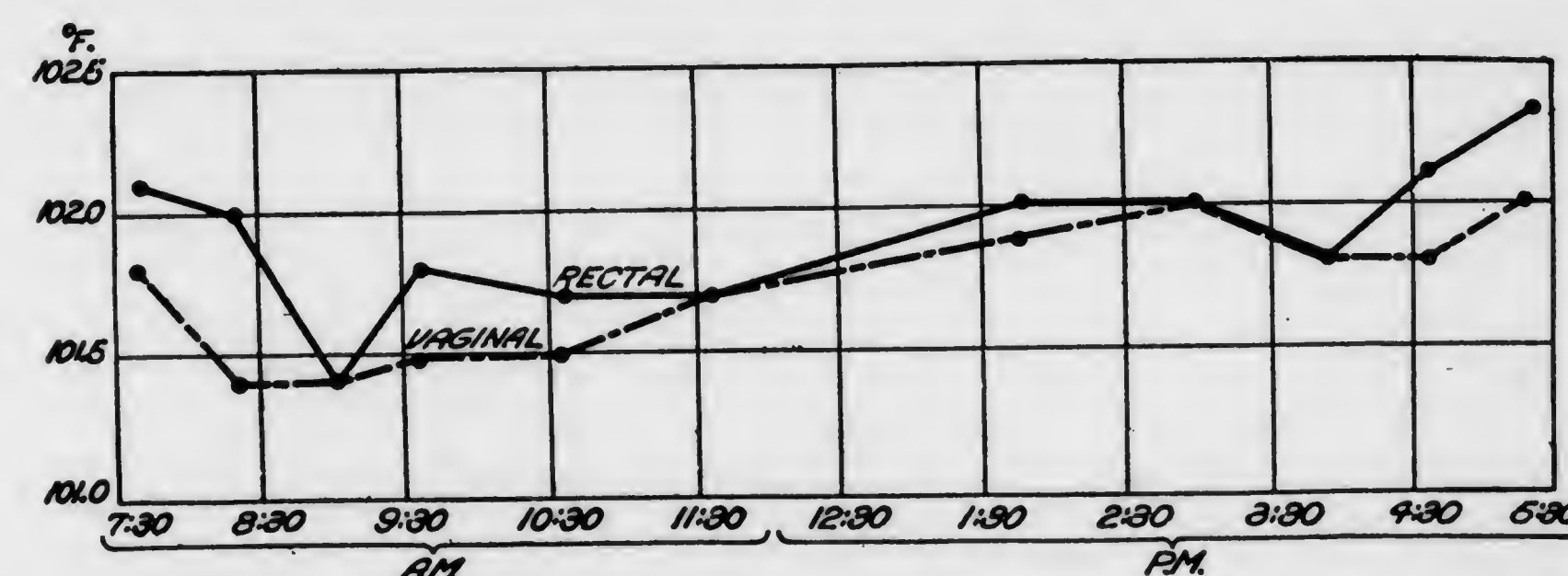


FIG. 2.—Variations in body temperature of cow 886 on December 2, 1919, 7.40 a. m. to 5.20 p. m. At 7.40 a. m. standing; 8.00 a. m. drank 13.0 kgm. of water at 48° F.; 8.20 a. m. lying; 9.00 a. m. standing and immediately after defecating; 9.35 a. m. to 10.35 a. m. lying; 2.57 p. m. standing; 3.55 p. m. lying down with thermometers inserted; 4.35 p. m. immediately after defecating; 5 p. m. to 5.20 p. m. eating.

The highest rectal temperature obtained was 102.2° F. at 4.30 p. m., while the lowest was 101.6° at 10 a. m. The highest vaginal temperature obtained was 101.9° at 4.30 p. m., while the lowest was 101.5° at 10.22 a. m. and 11.15 a. m.

OBSERVATIONS ON DECEMBER 2, 1919, WITH COW 886

Readings of the rectal and vaginal temperatures were taken at approximately 1-hour intervals from 7.40 a. m. to 11.35 a. m. and from 1.50 to 5.20 p. m. The rectal and vaginal temperatures were measured at the same time by the two thermometers. At 8 a. m. the cow drank 13 kgm. of water at 48° F. During the observations at 8.20 a. m., 9.35 a. m., and 10.35 a. m. the cow was lying; at 3.55 p. m. the cow lay down with the thermometers inserted. The cow was up during all the other readings. At 9 a. m. and at 4.35 p. m. the readings were taken immediately after defecation. The cow was fed at 5 p. m., and at the end of the observations—that is, at 5.20 p. m.—she was still eating. The results are given in figure 2.

The curve for the rectum, as in figure 1, shows a fall in temperature during the period following the drinking of the water. This drop is, however, more sudden and more noticeable, presumably on account of the greater amount of water drunk. The curve is quite uniform from 9.35 a. m. to 2.57 p. m., when it shows again a fall in temperature till 3.55 p. m., followed by a rise till 5.20 p. m.

The curve for the vagina is again lower than that for the rectum. It shows the effect of the water a little earlier than the rectal. During their course the two curves meet four times. There is, in general, however, some resemblance between figure 1 and figure 2.

The highest rectal temperature obtained was 102.3° F. at 5.20 p. m., while the lowest was 101.4° at 9 a. m. The highest vaginal temperature obtained was 102° at 5.20 p. m., while the lowest was 101.4° at 8.20 a. m. and at 9 a. m.

OBSERVATIONS ON DECEMBER 3, 1919, WITH COW 886

Readings of the rectal and vaginal temperatures were taken at approximately 1-hour intervals from 8.10 a. m. to 11 a. m. and from 1.30 p. m. to

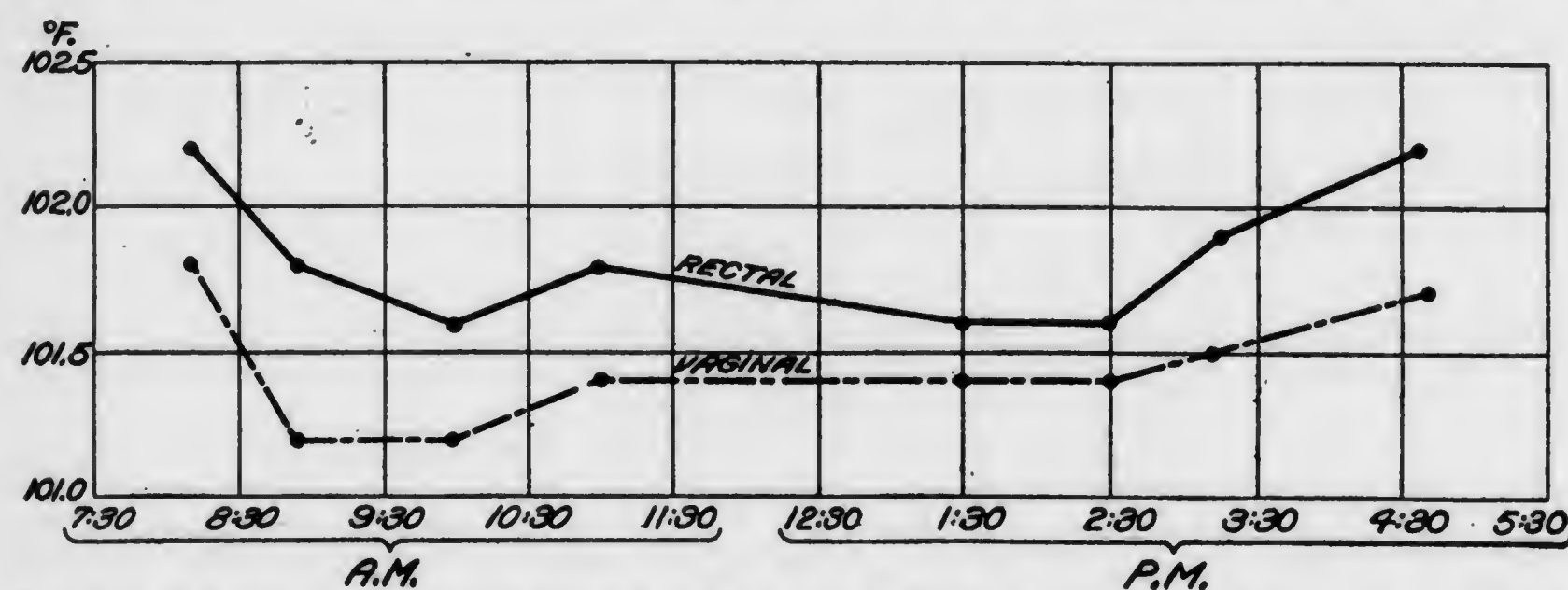


FIG. 3.—Variations in body temperature of cow 886 on December 3, 1919, 8.10 a. m. to 4.36 p. m. At 8 a. m. drank 13.0 kgm. of water at 55° F.; 8.10 a. m. to 8.54 a. m. standing; 10 a. m. immediately after getting up and defecating; 11 a. m. lying; 1.30 p. m. to 4.46 p. m. standing; 3.15 p. m. immediately after defecating; 4.36 p. m. immediately after defecating.

4.36 p. m. The rectal and vaginal temperatures were measured simultaneously by means of the two thermometers interchanged—that is, the one used on December 2 for the rectum was used here for the vagina, and vice versa. At 8 a. m. the cow drank 13 kgm. of water at 55° F. At 11 a. m. the cow was lying. During all other observations the cow was up. The readings at 10 a. m., 3.15 p. m., and 4.36 p. m. were taken immediately after defecation. The results of these observations are given in figure 3.

The curves show the usual fall in temperature after watering and the rise in temperature in the afternoon. The curve for the vagina is lower than that for the rectum and is to a great degree parallel with it.

The highest rectal temperature obtained was 102.2° F. at 8.10 a. m. and 4.36 p. m., while the lowest was 101.6° at 10 a. m. and 2.30 p. m. The

highest vaginal temperature obtained was 101.8° at 8.10 a. m., while the lowest was 101.2° at 8.54 a. m. and at 10 a. m.

OBSERVATIONS ON DECEMBER 4, 1919, WITH COW 886

Observations on the rectal and vaginal temperatures were made at approximately 1-hour intervals from 7.45 a. m. to 5.24 p. m. The rectal and vaginal temperatures were measured simultaneously with the two thermometers, as on the preceding day. At 8.05 a. m. the cow drank 9 kgm. of water at 54° F. During the readings at 8.57 a. m. and 2.24 p. m. the cow was lying, while during all others she was standing. At 9.33 a. m. the reading was taken immediately after defecation. From 5 p. m. to 5.24 p. m. the cow was eating. The results are represented by figure 4.

The curves show the usual fall in temperature after watering and the rise in the afternoon. The vaginal curve is lower than the rectal, meeting the latter at only one point, at 3.30 p. m.

The highest rectal temperature obtained was 102.2° F. at 4.24 p. m. and 5.24 p. m., while the lowest was 101.6° from 10.42 a. m. to 2.24 p. m.

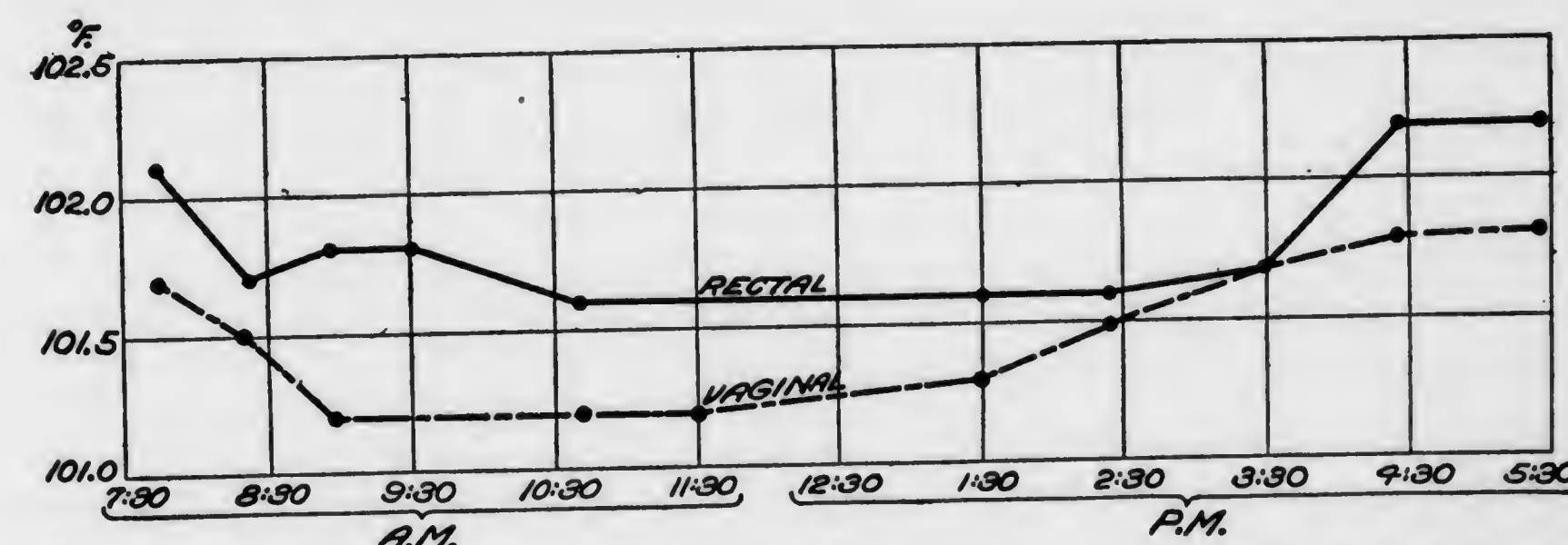


FIG. 4.—Variations in body temperature of cow 886 on December 4, 1919, 7.45 a. m. to 5.24 p. m. From 7.45 a. m. to 8.24 a. m. standing; 8.05 a. m. drank 9 kgm. of water at 54° F.; 8.57 a. m. lying; 9.33 a. m. immediately after getting up and defecating; 10.42 a. m. to 1.30 p. m. standing; 2.24 p. m. lying; 3.30 p. m. to 5.24 p. m. standing; 5 p. m. to 5.24 p. m. eating.

The highest vaginal temperature obtained was 101.8° at 4.24 p. m. and 5.24 p. m., while the lowest was 101.2° from 8.57 a. m. to 11.30 a. m.

OBSERVATIONS ON DECEMBER 5, 1919, WITH COW 886

Observations on the rectal and vaginal temperatures were made at approximately 1-hour intervals from 7.45 a. m. to 11.24 a. m. and from 1.36 p. m. to 5.24 p. m. The rectal and vaginal temperatures were measured at the same time with the two thermometers as on December 2 (fig. 2). At 8 a. m. the cow drank 6 kgm. of water at 54° F. At 7.45 a. m., 9.42 a. m., 11.24 a. m., and 1.36 p. m. the cow was lying; during the other readings she was standing. At 10.36 a. m. and at 3.18 p. m. the readings were taken immediately after defecation. From 5 p. m. to 5.24 p. m. the cow was eating. The results are represented by figure 5.

The peculiar feature of these curves is that the vaginal curve crosses the rectal at two points, besides meeting at another. The usual fall in temperature after watering and the rise in the afternoon are also shown.

The highest rectal temperature obtained was 102.3° F. at 7.45 a. m., while the lowest was 101.45° at 3.18 p. m. The highest vaginal temperature obtained was 102° at 7.45 a. m. and 5.24 p. m., while the lowest was 101.4° at 8.27 a. m., 10.36 a. m., and 1.36 p. m.

OBSERVATIONS ON DECEMBER 1, 1919, WITH COW 885

Observations on the rectal and vaginal temperatures were made at approximately 1 hour intervals from 8.06 a. m. to 11.30 a. m. and from 1.30 p. m. to 4.30 p. m. The vaginal temperature was measured immediately after the rectal by the same thermometer. At 8.30 a. m. the cow drank 29.4 kgm. of water at 52° F. The cow was standing during

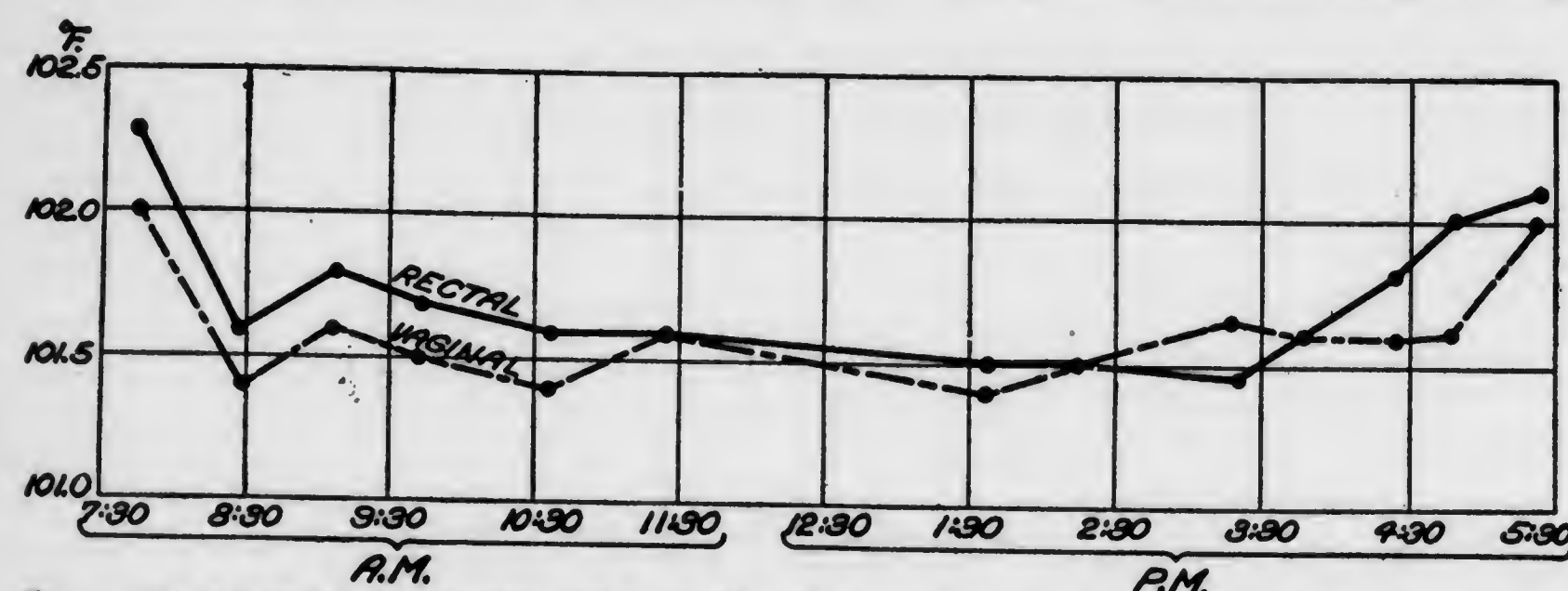


FIG. 5.—Variations in body temperature of cow 886 on December 5, 1919, 7.45 a. m. to 5.24 p. m. At 7.45 a. m. lying; 8 a. m. drank 6 kgm. of water at 54° F.; 8.27 a. m. standing; 9.06 a. m. and 9.42 a. m. lying; 10.36 a. m. immediately after getting up and defecating; 11.24 a. m. to 1.36 p. m. lying; 2.15 p. m. standing; 3.18 p. m. immediately after getting up and defecating; 3.42 p. m. to 5.24 p. m. standing; 5 p. m. to 5.24 p. m. eating.

all readings. At 8.12 a. m., 10.12 a. m., and 2.30 p. m. the readings were taken immediately after defecation. The results are represented by figure 6.

The peculiar feature of these curves is the very marked effect of the large quantity of water drunk. The vaginal is lower than the rectal curve and is almost parallel with it, meeting it, however, at two points. The usual rise in temperature in the afternoon is also shown.

The highest rectal temperature obtained was 102.2° F. at 4.30 p. m., while the lowest was 100.2° at 10.12 a. m. The highest vaginal temperature obtained was 101.7° at 8.12 a. m., while the lowest was 100.2° at 10.12 a. m.

OBSERVATIONS ON DECEMBER 2, 1919, WITH COW 885

Readings of the rectal and vaginal temperatures were taken at approximately 1-hour intervals from 7.48 a. m. to 10.45 a. m. and from 2 p. m. to 5.30 p. m. The rectal and vaginal temperatures were measured at the same time with the two thermometers as for figures 2 and 5. At

about 8 a. m. the cow was offered water, but she refused to drink. At 7.48 a. m. the cow was lying; during all other readings she was standing. At 9.25 a. m. the reading was taken immediately after the cow had urinated. At 7.48 a. m., 3.10 p. m., 5 p. m., and 5.30 p. m. the read-

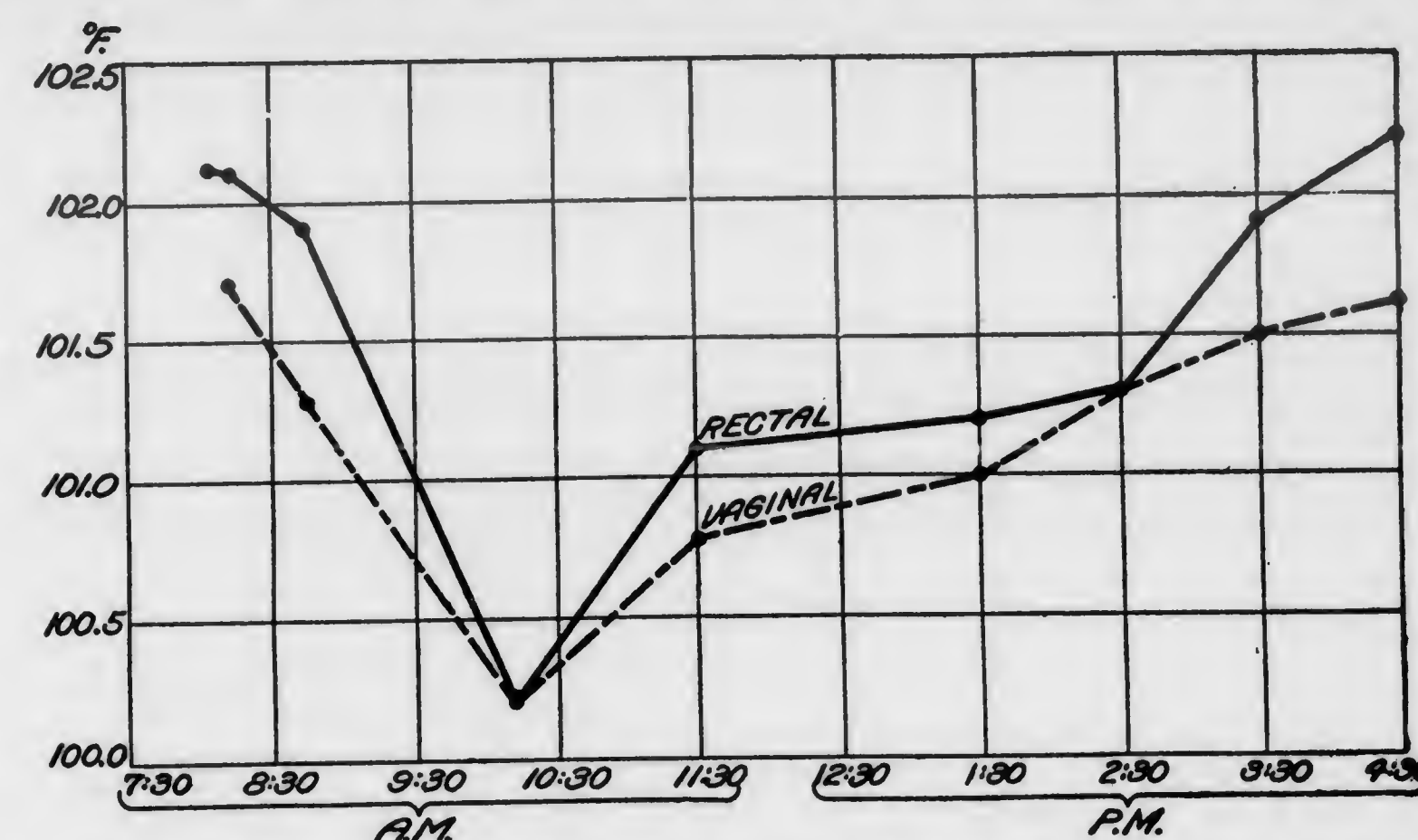


FIG. 6.—Variations in body temperature of cow 885 on December 1, 1919, 8.06 a. m. to 4.30 p. m. From 8.06 a. m. to 4.30 p. m. standing; 8.12 a. m. immediately after defecating; 8.30 a. m. drank 29.4 kgm. of water at 52° F.; 10.12 a. m. immediately after urinating and defecating; 2.30 p. m. after defecating.

ings were taken immediately after defecation. From 5 p. m. to 5.30 p. m. the cow was eating. The results are represented by figure 7.

The striking feature of these curves is that they are very much smoother than the preceding ones. The drop in temperature in the morning is lacking, apparently, because the cow did not drink any water. The curves show instead a very gradual and slight fall in temperature till

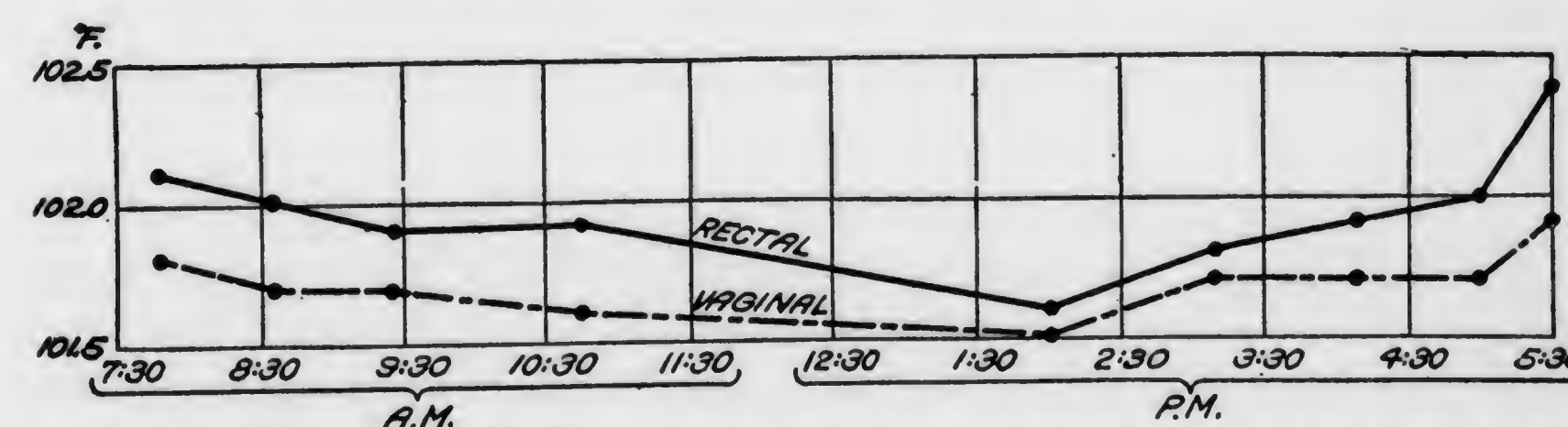


FIG. 7.—Variations in body temperature of cow 885 on December 2, 1919, 7.48 a. m. to 5.30 p. m. At 7.48 a. m. lying and immediately after defecating; 8.36 a. m. to 5.30 p. m. standing; cow drank no water; 9.25 a. m. immediately after urinating; 3.10 p. m. immediately after defecating; 5 p. m. immediately after defecating; 5 p. m. to 5.30 p. m. eating; 5.30 p. m. immediately after defecating.

2 p. m., and from that time a gradual rise. The vaginal curve is lower than the rectal and runs almost parallel with it, not meeting it at any point.

The highest rectal temperature obtained was 102.4° F. at 5.30 p. m., while the lowest was 101.6° at 2 p. m. The highest vaginal temperature obtained was 101.9° at 5.30 p. m., while the lowest was 101.5° at 2 p. m.

OBSERVATIONS ON DECEMBER 3, 1919, WITH COW 885

Readings of the rectal and vaginal temperatures were taken at approximately 1-hour intervals from 8.20 a. m. to 11.12 a. m. and from 1.38 p. m. to 4.48 p. m. The rectal and vaginal temperatures were measured at the same time with the two thermometers interchanged—that is, the one used in figure 7 for the rectum was used here for the vagina, and vice versa. At 8.05 a. m. the cow drank 22 kgm. of water at 55° F. The cow was standing during all observations. At 9 a. m. and 10.12 a. m. the readings were taken immediately after defecation. The results are given in figure 8.

The curves show a marked fall in temperature after the watering. The vaginal is lower than the rectal curve and runs parallel with it.

The highest rectal temperature obtained was 101.9° F. at 2.45 p. m., while the lowest was 100.7° at 9 a. m. The highest vaginal temperature

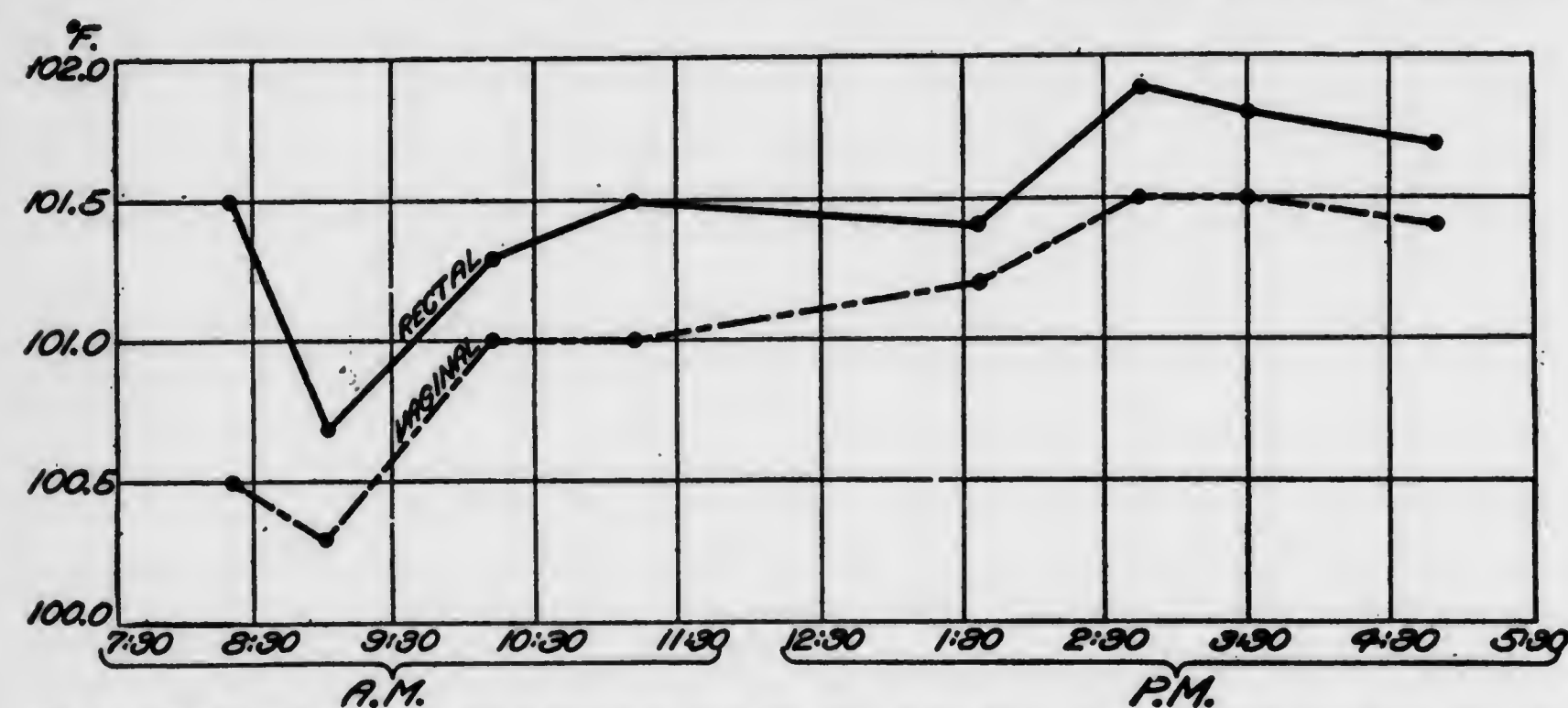


FIG. 8.—Variations in body temperature of cow 885 on December 3, 1919, 8.20 a. m. to 4.48 p. m. At 8.05 a. m. drank 22 kgm. of water at 55° F.; 9 a. m. immediately after defecating; 10.12 a. m. immediately after defecating; cow standing during all observations.

obtained was 101.5° at 2.45 p. m. and 3.30 p. m., while the lowest was 100.3 at 9 a. m.

OBSERVATIONS ON DECEMBER 4, 1919, WITH COW 885

Observations on the rectal and vaginal temperatures were made at approximately 1-hour intervals from 8 a. m. to 11.36 a. m. and from 1.42 p. m. to 5.30 p. m. The rectal and vaginal temperatures were measured at the same time by the two thermometers as on December 3. At about 8 a. m. the cow was offered water, but she refused to drink. At 10.54 a. m. the cow was lying; during all other observations she was standing. At 9.12 a. m. and 4.45 p. m. the readings were taken immediately after defecation. From 5 p. m. to 5.30 p. m. the cow was eating. The results are represented by figure 9.

The curves show irregularity for the first three hours but are much smoother for the rest of the day. Although meeting each other at the very start, the curves soon diverge and the vaginal remains considerably lower than the rectal throughout their course.

The highest rectal temperature obtained was 102.2° F. at 5.30 p. m., while the lowest was 101.6° at 8 a. m. The highest vaginal temperature obtained was 101.8° at 5.30 p. m., while the lowest was 101.2° at 9.12 a. m., 11.36 a. m., and 1.42 p. m.

OBSERVATIONS ON DECEMBER 5, 1919, WITH COW 885

Readings of the rectal and vaginal temperatures were taken at approximately 1-hour intervals from 7.57 a. m. to 11.30 a. m. and from 1.48 p. m. to 5.30 p. m. The rectal and vaginal temperatures were measured at the same time by the two thermometers as on December 2. At 8.10 a. m. the cow drank 23 kgm. of water at 54° F. The cow was standing during all the readings, except at 9.30 a. m. The readings at 7.57 a. m., 8.45 a. m., 10.42 a. m., and 5.30 p. m. were taken immediately after defecation. From 5 p. m. to 5.30 p. m. the cow was eating. The results are represented by figure 10.

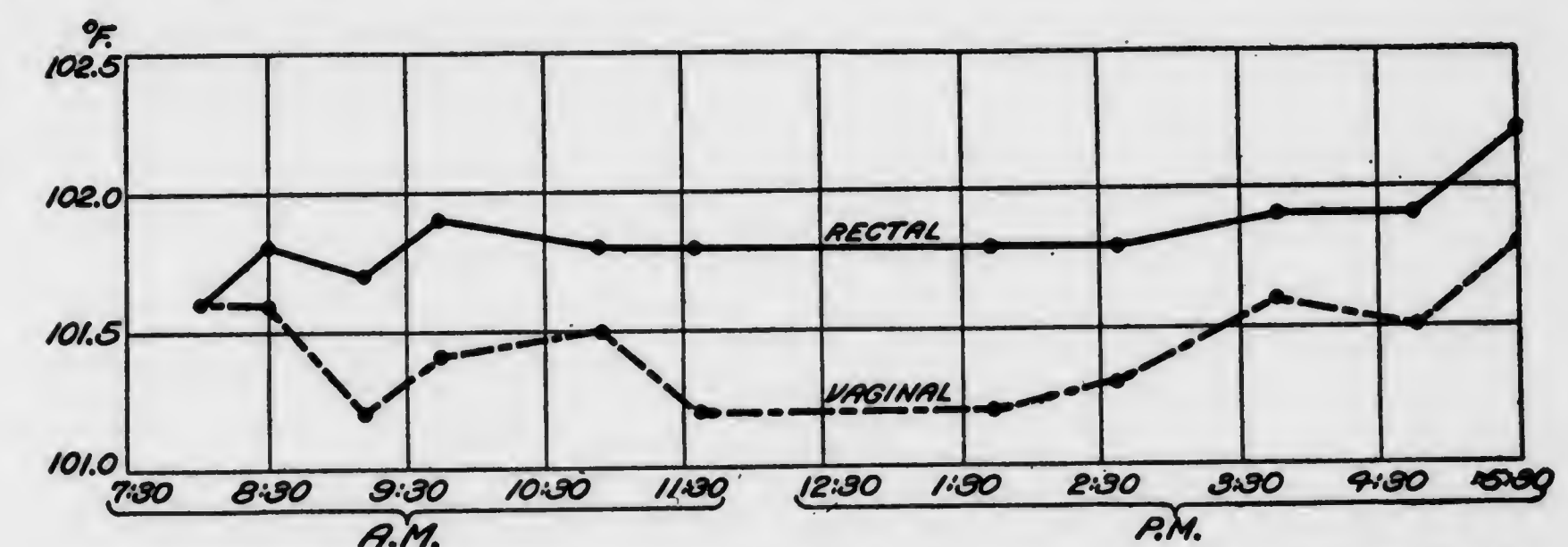


FIG. 9.—Variations in body temperature of cow 885 on December 4, 1919, 8 a. m. to 5.30 p. m. Cow drank no water; 8 a. m. immediately after defecating, standing; 9.12 a. m. immediately after defecating, standing; 10.54 a. m. lying; 11.36 a. m. to 5.30 p. m. standing; 4.45 p. m. immediately after defecating; 5 p. m. to 5.30 p. m. eating.

The curves show a striking resemblance to those in figure 6, showing in about the same way the effect of water drunk, the rise in temperature in the afternoon, as well as the relative positions of the vaginal and rectal curves.

The highest rectal temperature obtained was 102° F. at 5.30 p. m., while the lowest was 100.4° from 8.45 a. m. to 8.56 a. m. The highest vaginal temperature obtained was 101.6° at 5.30 p. m., while the lowest was 99.9° at 8.56 a. m.

GENERAL CONCLUSIONS WITH REGARD TO THE VARIATIONS IN BODY TEMPERATURE FROM ABOUT 7.30 A. M. TO ABOUT 5.30 P. M.

All the foregoing observations indicate that, in cows, the vaginal temperature is decidedly lower than the rectal, when measured at the same depth of 7 inches, while a trend toward parallelism between the two is also apparent. This can be, at least partially, explained by the fact that the vagina is more exposed to the outside atmosphere than is the rectum. For determinations of the average body temperature the

rectum, therefore, is to be preferred to the vagina as a place for inserting the thermometer.

A fall in temperature invariably follows the drinking of water. This fall varies with the quantity of water drunk. Consequently, the first two or three hours after watering do not afford a good time for comparative determinations of body temperature.

After the body has overcome the effect of the water, the temperature appears quite uniform for about three hours, after which there is a gradual

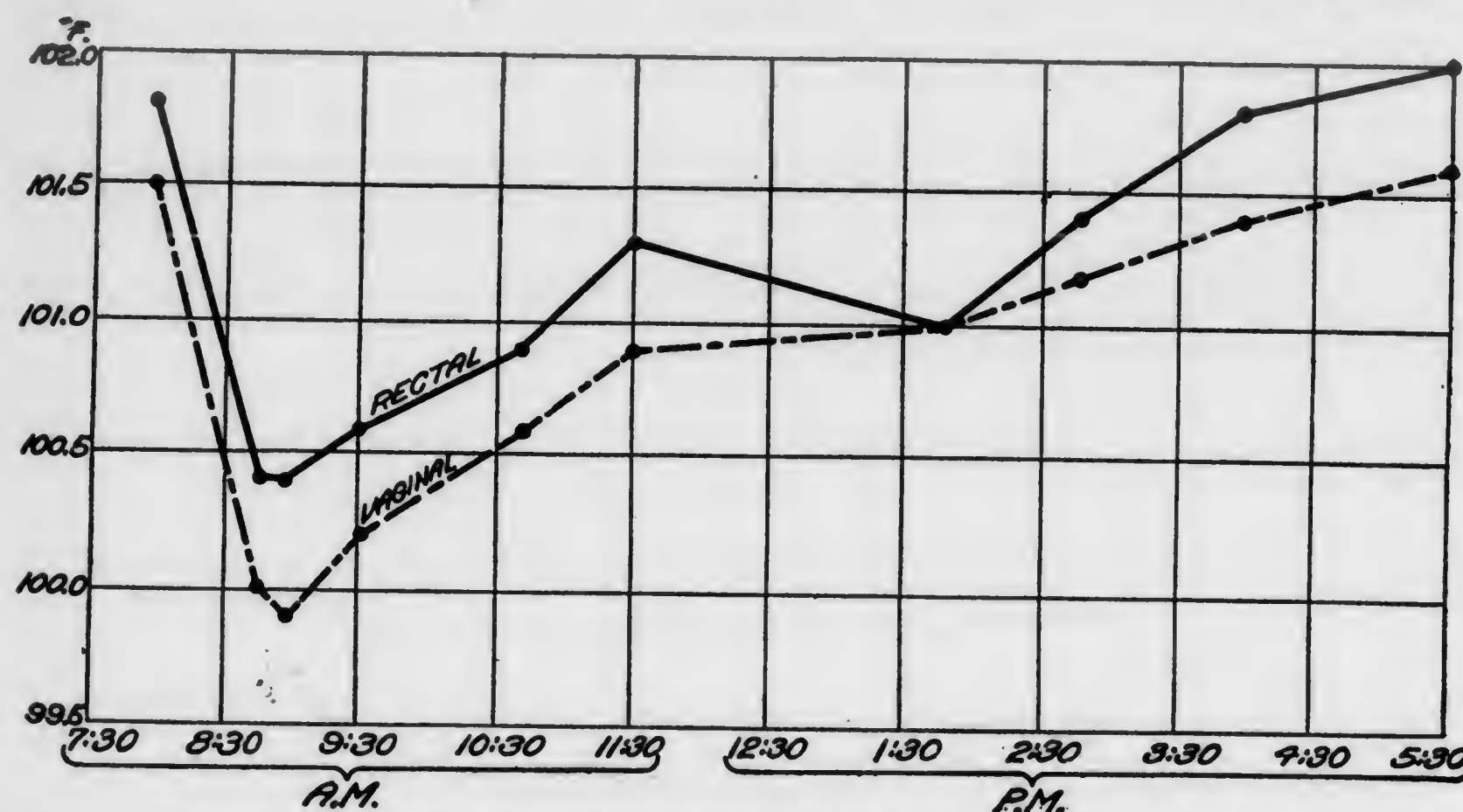


FIG. 10.—Variations in body temperature of cow 885 on December 5, 1919, 7.57 a. m. to 5.30 p. m. At 7.57 a. m. immediately after defecating, standing; 8.10 a. m. drank 23 kgm. at 54° F.; 8.45 a. m. immediately after defecating; 9.30 a. m. lying; 10.42 a. m. immediately after defecating, standing; 5 p. m. to 5.30 p. m. eating; 5.30 p. m. immediately after defecating.

rise which reaches its maximum at about 5.30 p. m. The accelerated rise, however, from 5 p. m. to 5.30 p. m. may be due to the eating.

Since the exact time when the animal changed its position was not recorded during these observations, no definite conclusions can be drawn as to what effect the position of the animal has on the body temperature.

The act of defecation did not produce any noticeable effect.

The highest rectal temperature obtained during this series of observations was 102.4° F. at 5.30 p. m. (fig. 7). The lowest rectal temperature was 100.2° at 10.12 a. m. (fig. 6). The highest vaginal temperature obtained was 102° at 2.57 p. m., 5.20 p. m. (fig. 2), and 5.24 p. m. (fig. 5), while the lowest was 99.9° at 8.56 a. m. (fig. 10).

OBSERVATIONS ON THE THERMAL GRADIENT

Recent investigations on the body temperature of man¹ and other animals² show that variations in body temperature depend to a very great extent on the depth to which the thermometer is inserted, and that

¹ BENEDICT, Francis G., and SLACK, Edgar P. A COMPARATIVE STUDY OF TEMPERATURE FLUCTUATIONS IN DIFFERENT PARTS OF THE HUMAN BODY. V, 73 p., illus. Washington, D. C., 1911. (Carnegie Inst. Washington Pub. 155.)

² LIPSCHÜTZ, Alexander. ÜBER DIE ABHÄNGIGKEIT DER KÖRPERTEMPERATUR VON DER PUBERTÄTS-DRÜSE. In Arch. Gesam. Physiol., Bd. 168, Heft 1/4, p. 177-192, 1 fig. 1917.

the thermal gradient rises sharply for the first few centimeters beneath the surface of the skin and soon reaches a point beyond which the body temperature is not materially increased. To reach this point in man¹ and in the guinea pig² 6 or 7 cm. were found to be sufficient. The following observations were made with the view of testing out these findings on cows.

OBSERVATIONS ON THERMAL GRADIENT, WITH COW 886 ON DECEMBER 5, 1919, 2.09 P. M. TO 3.18 P. M.

Observations on the rectal and vaginal temperatures were made simultaneously with the two thermometers. The thermometers were first inserted 4 inches deep, then 5 inches, then 7 inches, then 6 inches, and finally again 7 inches. The results are represented by figure 11, and the actual temperature observations, the time, and the insertions are given in Table I.

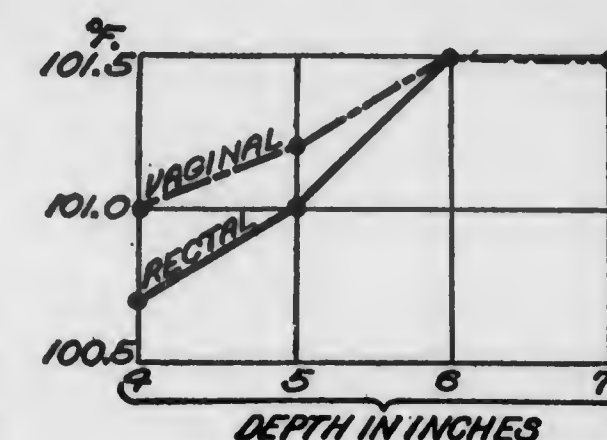


FIG. 11.—Observations on thermal gradient with cow 886 on December 5, 1919, 2.09 p. m. to 3.18 p. m.

TABLE I.—Thermal gradient observations

Time.	Rectal temperature.	Vaginal temperature.	Depth inserted.
	° F.	° F.	Inches.
2.09 p. m...	100.7	101.0	4
2.12 p. m...	101.0	101.2	5
2.15 p. m...	101.5	101.5	7
2.24 p. m...	101.5	101.5	6
3.18 p. m...	101.5	.....	7

The results show that at a depth of 4 inches the rectal temperature was 0.80° F. lower than at a depth of either 6 or 7 inches, while it was only 0.3° lower than at a depth of 5 inches. The vaginal temperature was 0.2° lower at a depth of 4 inches than at a depth of 5 inches and 0.5° lower than at a depth of either 6 or 7 inches. There was no rise in temperature between 6 and 7 inches—that is, the maximum body temperature was reached in this case when the thermometer was inserted 6 or 7 inches into the rectum or the vagina. Up to a depth of 6 inches the vaginal curve appears higher than the rectal.

OBSERVATIONS ON THERMAL GRADIENT, WITH COW 886, ON DECEMBER 5, 1919, 3.25 P. M. TO 3.42 P. M.

Readings of the rectal and vaginal temperatures were taken simultaneously as before. The thermometers were first inserted 6 inches deep, then 5 inches, then 4 inches, and finally 7 inches. The results are represented by figure 12, and the actual temperature observations, the time and the insertions are given in Table II.

¹ BENEDICT, Francis G., and SLACK, Edgar P. OP. CIT.

² LIPSCHÜTZ, Alexander. OP. CIT.

TABLE II.—Thermal gradient observations

Time.	Rectal temperature.	Vaginal temperature.	Depth inserted.
	° F.	° F.	Inches.
3.25 p. m.	101.4	101.5	6
3.30 p. m.	101.2	101.5	5
3.36 p. m.	100.5	101.2	4
3.42 p. m.	101.6	101.6	7

The results show a very rapid rise between 4 and 5 inches, while beyond that point the rise is much slower. In this case there was a slight rise in temperature from 6 to 7 inches. However, it is very likely that this rise is due not to this difference in depth but to the difference in time,

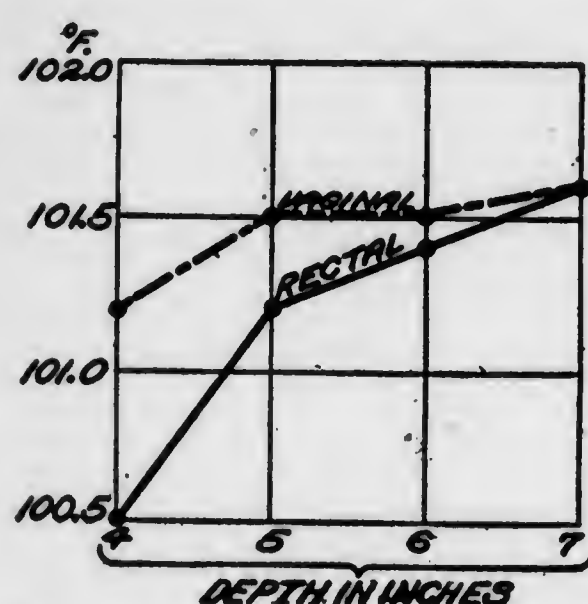


FIG. 12.—Observations on thermal gradient with cow 886 on December 5, 1919, 3.25 p. m. to 3.42 p. m.

since there was an interval of 17 minutes between the two readings and the tendency of the body temperature is to rise in the afternoon. The vaginal curve is higher than the rectal, but they meet at a depth of 7 inches.

OBSERVATIONS ON THERMAL GRADIENT WITH COW 885 ON DECEMBER 5, 1919, 4 P. M. TO 4.18 P. M.

Readings of the rectal and vaginal temperatures were taken simultaneously by the two thermometers as before. The thermometers were inserted first 6 inches deep, then 7 inches, then 4 inches, and finally 5 inches. The results are represented by figure 13, and the actual temperature observations, the time, and the insertions are given in Table III.

TABLE III.—Thermal gradient observations

Time.	Rectal temperature.	Vaginal temperature.	Depth inserted.
	° F.	° F.	Inches.
4.00 p. m.	101.7	101.3	6
4.03 p. m.	101.8	101.4	7
4.10 p. m.	101.4	101.0	4
4.18 p. m.	101.5	101.2	5

The results show a very gradual rise from 4 inches to 7 inches, the difference being only 0.4° F. The order in which the readings were taken is significant in showing that despite the tendency of the body temperature to rise at this time of the day, the 4- and 5-inch insertions show a lower temperature than the latter. The vaginal curve is in this case lower than the rectal and is parallel with it.

OBSERVATIONS ON THERMAL GRADIENT WITH COW 886 ON DECEMBER 5, 1919, 4.24 P. M. TO 4.42 P. M.

Observations on the rectal and vaginal temperatures were made simultaneously by means of the two thermometers as before. The thermometers were first inserted 7 inches deep, then 6 inches, then 5 inches, and finally 4 inches. The results are represented by figure 14, and the actual temperature observations, the time, and the insertions are given in Table IV.

TABLE IV.—Thermal gradient observations

Time.	Rectal temperature.	Vaginal temperature.	Depth inserted.
	° F.	° F.	Inches.
4.24 p. m.	101.8	101.6	7
4.30 p. m.	101.8	101.6	6
4.36 p. m.	101.7	101.5	5
4.42 p. m.	101.5	101.2	4
4.48 p. m.	102.0	101.6	7

The results show a more rapid rise in temperature from a depth of 4 to 5 inches than from 5 to 6 inches. There is no change in temperature from a depth of 6 to a depth of 7 inches, thus indicating that the maximum

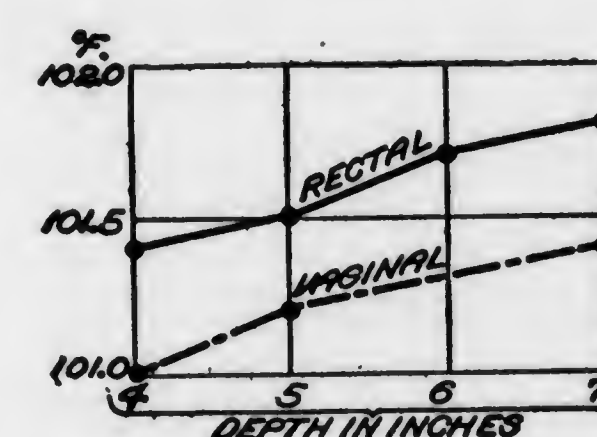


FIG. 13.—Observations on thermal gradient with cow 885 on December 5, 1919, 4 p. m. to 4.18 p. m.

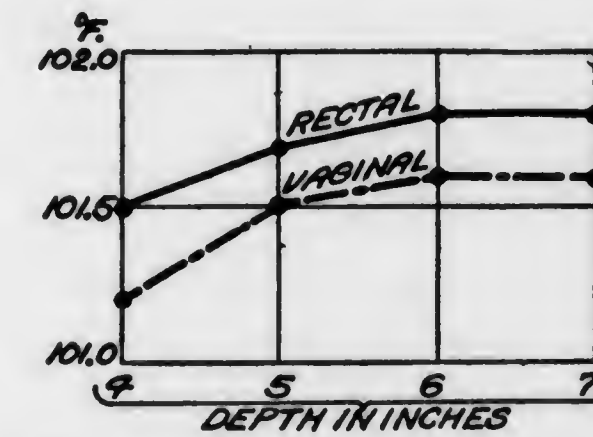


FIG. 14.—Observations on thermal gradient with cow 886 on December 5, 1919, 4.24 p. m. to 4.42 p. m.

temperature was in this case reached at a depth of 6 inches. The reading at 4.48 p. m. is given in the table to show the effect of the time of day. The vaginal curve is lower than the rectal and is parallel with it.

GENERAL CONCLUSIONS WITH REGARD TO THE THERMAL GRADIENT

From a consideration of the results given above it is apparent that the thermal gradient between the temperature at a depth of 4 inches and at a depth of 6 inches is noticeable, while there is no material change between a depth of 6 inches and a depth of 7 inches. It may be concluded, therefore, that at a depth of 7 inches the body temperature is essentially at its maximum. This does not show, of course, that the temperature may not be actually higher in some other parts of the body, where there is a specific metabolic activity, but it does show that it is

much safer in the determinations of the average body temperature of a cow to insert the thermometer to a depth of 7 inches than to a depth of 4 or 5 inches.

The fact that the vaginal curve below 6 or 7 inches is in some cases higher than the rectal (fig. 11, 12) and in some cases lower (fig. 13, 14) illustrates the inconstancy of the temperature when measured at a depth below 6 inches.

VARIATIONS IN BODY TEMPERATURE FROM ABOUT 5 P. M. TO ABOUT 7 P. M.

The purpose of making temperature observations from about 5 p. m. to about 7 p. m. is twofold: First, to study the effect of the feed on the body temperature and, second, to get some idea as to the temperature fluctuations at 6 p. m., the time representing the beginning as well as

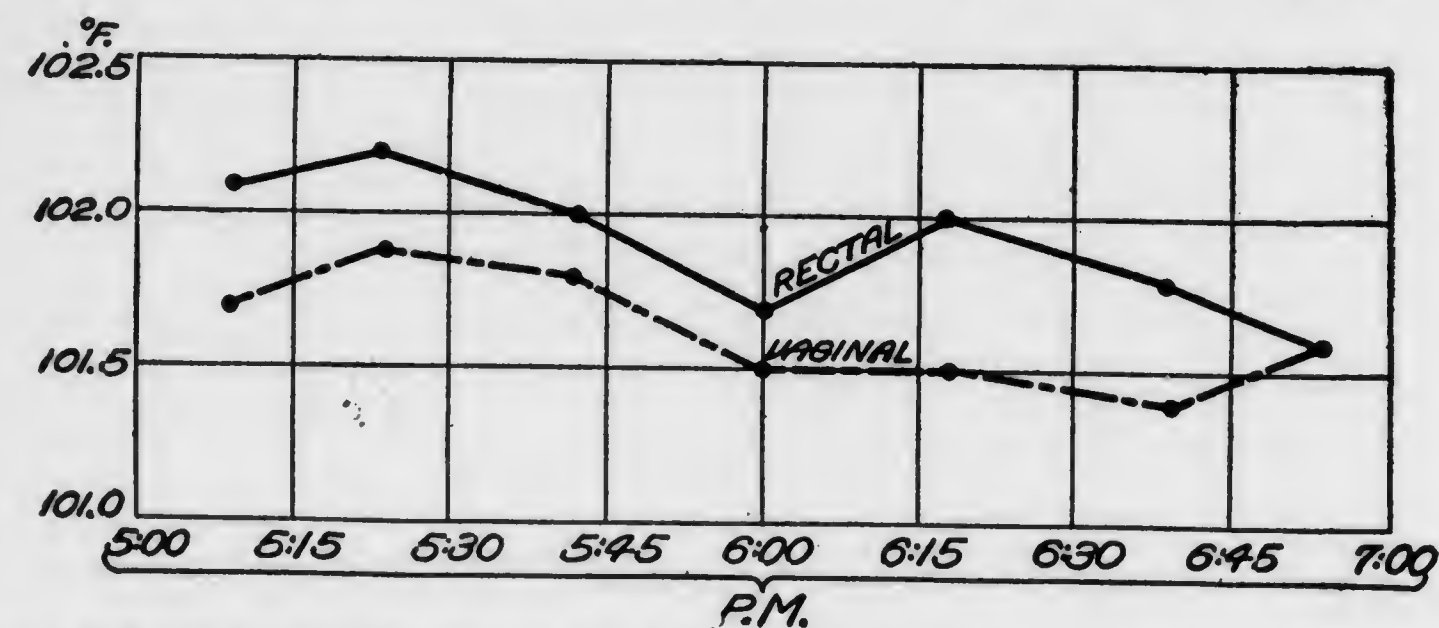


FIG. 15.—Variations in body temperature of cow 886 on December 9, 1919, 5.10 p. m. to 6.54 p. m. From 5 p. m. to 5.42 p. m. eating; 6.18 p. m. to 6.54 p. m. lying.

the end of experimental periods in the respiration calorimeter experiments at the Institute.

OBSERVATIONS ON DECEMBER 9, 1919, WITH COW 886

Observations on the rectal and vaginal temperatures were made at approximately 15-minute intervals from 5.10 p. m. to 6.54 p. m. The cow was eating from 5 p. m. to 5.42 p. m. From 6.18 p. m. to 6.54 p. m. she was lying. The results are represented by figure 15.

The curves show a slight rise in temperature from 5.10 p. m. to 5.25 p. m., followed by a gradual fall till 6 p. m. After 6 p. m. the rectal curve again shows a rise till 6.18 p. m., followed by a gradual drop till 6.54 p. m., when it meets the vaginal curve. The vaginal curve is lower than the rectal and is parallel with it only till 6 p. m.

OBSERVATIONS ON DECEMBER 10, 1919, WITH COW 886

Readings of the rectal and vaginal temperatures were taken at approximately 15-minute intervals from 5 p. m. to 6.30 p. m. From 5 p. m. to 5.36 p. m. the cow was eating. The reading at 5 p. m. was taken immediately after defecation. The cow was lying from 6.03 p. m. to 6.30 p. m. The results are given in figure 16.

The curves show, in general, a slight and gradual drop. It should be noted that the initial temperature—that is, the temperature at 5 p. m.—was rather high.

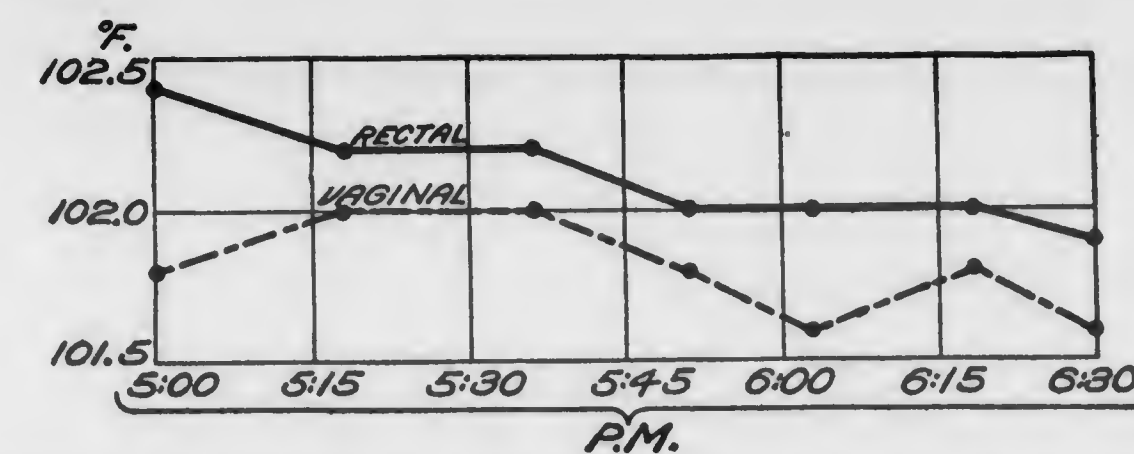


FIG. 16.—Variations in body temperature of cow 886 on December 10, 1919, 5 p. m. to 6.30 p. m. From 5 p. m. to 5.36 p. m. eating; 5 p. m. immediately after defecating; 6.03 p. m. to 6.30 p. m. lying.

OBSERVATIONS ON DECEMBER 11, 1919, WITH COW 886

Readings of the rectal and vaginal temperatures were taken at approximately 15-minute intervals from 4.52 p. m. to 6.36 p. m. From 5 p. m. to 5.48 p. m. the cow was eating. From 6.21 p. m. to 6.36 p. m. she was lying. The results are represented by figure 17.

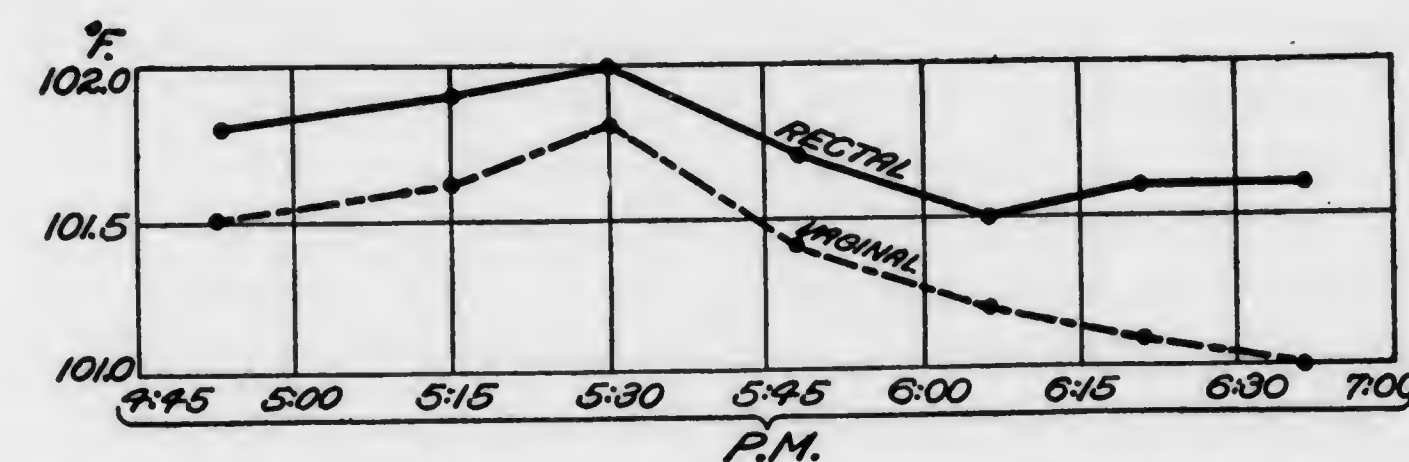


FIG. 17.—Variations in body temperature of cow 886 on December 11, 1919, 4.52 p. m. to 6.36 p. m. From 5 p. m. to 5.48 p. m. eating; 6.21 p. m. to 6.36 p. m. lying.

The curves show a gradual rise in temperature till 5.30 p. m., followed by a fall which is continuous in the vaginal temperature but is interrupted by a very slight rise in the rectal temperature at 6.21 p. m., the time the cow lay down. The two curves are nearly parallel.

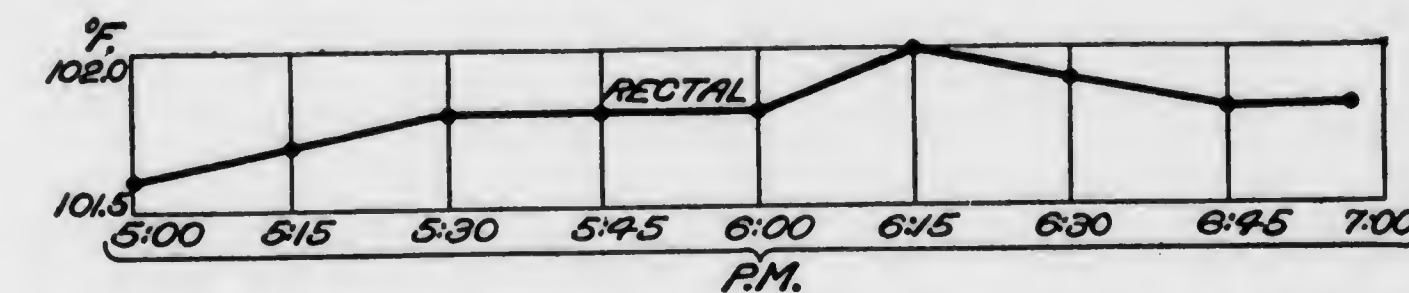


FIG. 18.—Variations in body temperature of cow 886 on December 13, 1919, 5 p. m. to 6.57 p. m. From 5 p. m. to 5.30 p. m. eating; 6.15 p. m. to 6.57 p. m. lying.

OBSERVATIONS ON DECEMBER 13, 1919, WITH COW 886

Observations on the rectal temperature were made at about 15-minute intervals from 5 p. m. to 6.57 p. m. From 5 p. m. to 5.30 p. m. the cow was eating. From 6.15 p. m. to 6.57 p. m. she was lying. The results are given in figure 18.

The curve shows, in general, a gradual rise till 6.15 p. m., the time the cow lay down, followed by a slight and gradual drop.

OBSERVATIONS ON DECEMBER 14, 1919, WITH COW 886

Observations on the rectal temperature were made at approximately 15-minute intervals from 5.06 p. m. to 6.21 p. m. From 5 p. m. to 5.36 p. m. the cow was eating. From 5.50 p. m. to 6.21 p. m. she was lying. The results are represented by figure 19.

OBSERVATIONS ON JANUARY 12, 1920, WITH COW 886

Readings of the rectal temperature were taken at 15-minute intervals from 5 p. m. to 6 p. m. The cow was eating from 5 p. m. to 6 p. m. The results are given in figure 20.

The curve shows, in general, a gradual rise from 5 p. m. to 6 p. m. It should be mentioned that the cow received a supermaintenance ration at this date and that she spent the whole hour from 5 p. m. to 6 p. m. in eating.

OBSERVATIONS ON DECEMBER 11, 1919, WITH COW 885

Readings of the rectal and vaginal temperatures were taken at approximately 15-minute intervals from 5 p. m. to 6.30 p. m. From 5 p. m. to 5.42 p. m. the cow was eating. The reading at 5 p. m. was taken immediately after defecation. At 6.15 p. m. the cow defecated and pushed out the thermometer. The readings taken then and also immediately after defecation corresponded with each other. The cow was standing all the time. The results are given in figure 21.

The rectal curve shows a gradual rise in temperature till 5.42 p. m., the time the cow was through eating, followed by a slight fall in temperature till 6.15 p. m., followed again by a rise. The vaginal curve is much lower than the rectal.

OBSERVATIONS ON DECEMBER 13, 1919, WITH COW 885

Readings of the rectal temperature were taken at approximately 15-minute intervals from 5.12 p. m. to 7 p. m. From 5 p. m. to 5.35 p. m. the cow was eating. From 6.35 p. m. to 7 p. m. she was lying. The results are represented by figure 22.

The curve is, in a general way, similar to the rectal curve in figure 21.

OBSERVATIONS ON DECEMBER 14, 1919, WITH COW 885

Observations on the rectal temperature were made at approximately 15-minute intervals from 5.18 p. m. to 6.12 p. m. From 5 p. m. to 5.35 p. m. the cow was eating. The cow was up all the time. The results are given in figure 23.

The peculiar feature of this curve is the rather rapid drop from 5.30 p. m. to 6.12 p. m.



FIG. 19.—Variations in body temperature of cow 886 on December 14, 1919, 5.06 p. m. to 6.21 p. m. From 5 p. m. to 5.36 p. m. eating; 5.50 p. m. to 6.21 p. m. lying.

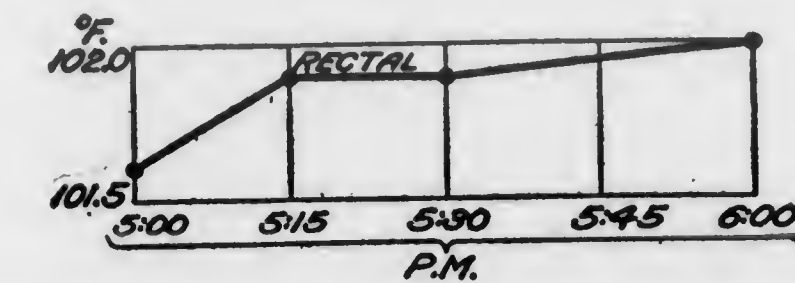


FIG. 20.—Variations in body temperature of cow 886 on January 12, 1920, 5 p. m. to 6 p. m. From 5 p. m. to 6 p. m. eating.

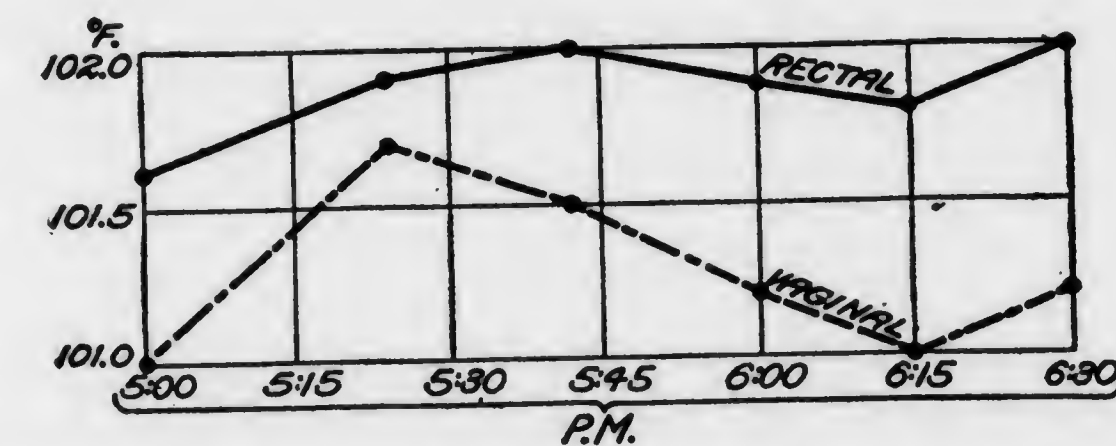


FIG. 21.—Variations in body temperature of cow 885 on December 11, 1919, 5 p. m. to 6.30 p. m. From 5 p. m. to 5.42 p. m. eating; 5 p. m. immediately after defecating; 6.15 p. m. immediately before and after defecating; cow standing all the time.

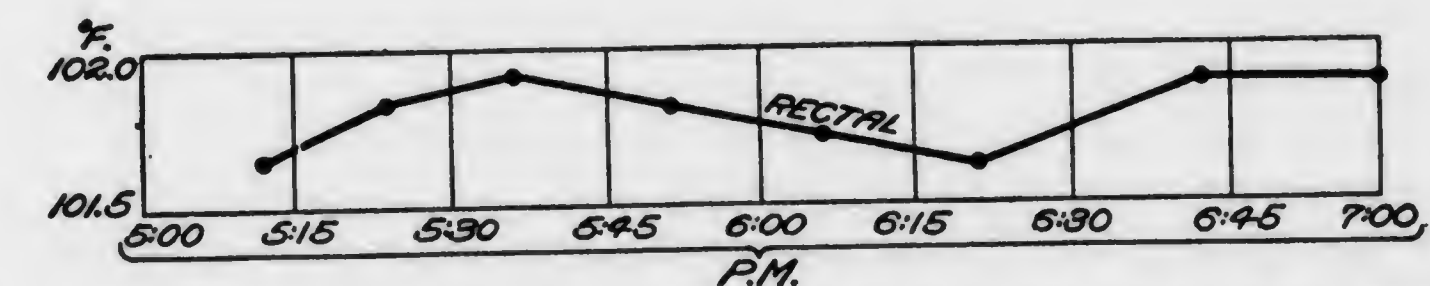


FIG. 22.—Variations in body temperature of cow 885 on December 13, 1919, 5.12 to 7 p. m. From 5 p. m. to 5.35 p. m. eating; 6.35 p. m. to 7 p. m. lying.

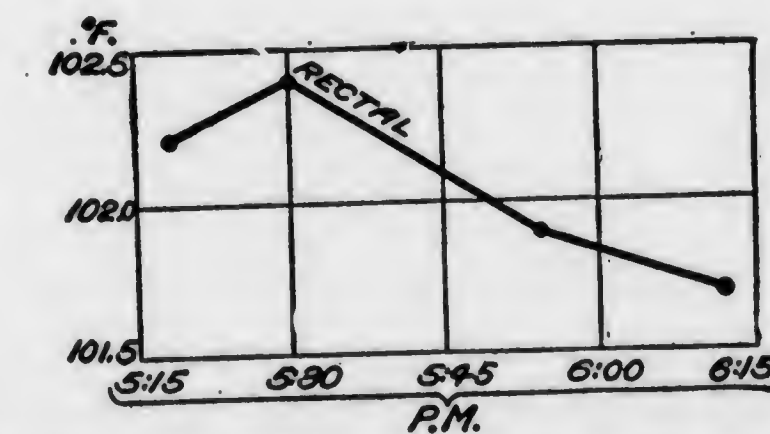


FIG. 23.—Variations in body temperature of cow 885 on December 14, 1919, 5.18 p. m. to 6.12 p. m. From 5 p. m. to 5.35 p. m. eating; cow standing all the time.

OBSERVATIONS ON JANUARY 4, 1920, WITH COW 885

Observations on the rectal temperature were made at approximately 15-minute intervals from 5 p. m. to 5.55 p. m. From 5 p. m. to 5.36 p. m. the cow was eating. The cow was up all the time. The results are represented by figure 24.

OBSERVATIONS ON JANUARY 4, 1920, WITH COW 886

Readings of the rectal temperature were made at 15-minute intervals from 5 p. m. to 6 p. m. The cow was not fed till 6 p. m. and was standing all the time. The results are represented by figure 25.

The peculiar feature of the curve is the fall in temperature till 5.30 p. m., followed by a rise from 5.30 p. m. to 6 p. m.

OBSERVATIONS ON MARCH 20, 1920, WITH COW 886

Two readings of the rectal temperature were taken between 5 p. m. to 6.25 p. m. The cow was not fed till 6.25 p. m. and was standing all the time. The results are given in figure 26.

The curve does not show any material change in temperature from 5.15 p. m. to 6.25 p. m.

OBSERVATIONS ON JANUARY 12, 1920, WITH COW 885

Readings of the rectal temperature were taken at approximately 20-minute intervals from 5 p. m. to 6.04 p. m. The cow was not fed till 6 p. m. and was standing all the time. The results are given in figure 27.

OBSERVATIONS ON FEBRUARY 16, 1920, WITH COW 885

Readings of the rectal temperature were taken at half-hour intervals from 5 p. m. to 6 p. m. The cow was not fed till 6 p. m. and was standing all the time. The results are given in figure 28.

The curve shows a fall in temperature from 5 p. m. to 5.30 p. m.

GENERAL CONCLUSIONS WITH REGARD TO THE VARIATIONS IN BODY TEMPERATURE FROM ABOUT 5 P. M. TO ABOUT 7 P. M.

A comparison of the temperature curves obtained when the cow was fed at 5 p. m. with those obtained when the cow was not fed till 6 p. m. shows, in general, that when the cow was fed at 5 p. m. there was a slight rise in temperature till about 5.30 p. m., followed by a slight fall. This rise from 5 p. m. till 5.30 p. m. has been noted in previous observations (fig. 2, 5, 7, 9, 10), when the cows were fed at 5 p. m. When, however, the cow was not fed till 6 p. m., the temperature in most cases not only did not rise from 5 p. m. to 5.30 p. m., but instead dropped slightly. This indicates that eating of the feed raises the body temperature slightly for about $\frac{1}{2}$ hour when the cows receive a maintenance ration.

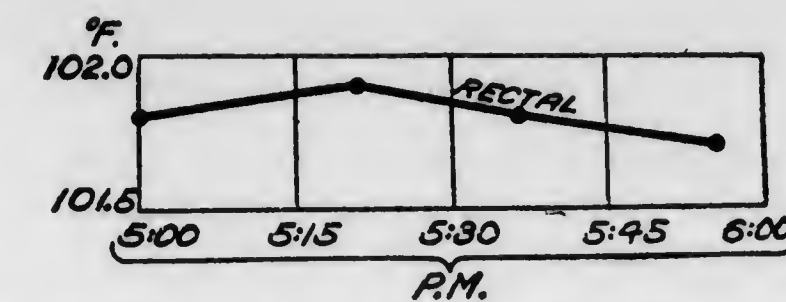


FIG. 24.—Variations in body temperature of cow 885 on January 4, 1920, 5 p. m. to 5.55 p. m. From 5 p. m. to 5.36 p. m. eating; cow standing all the time.

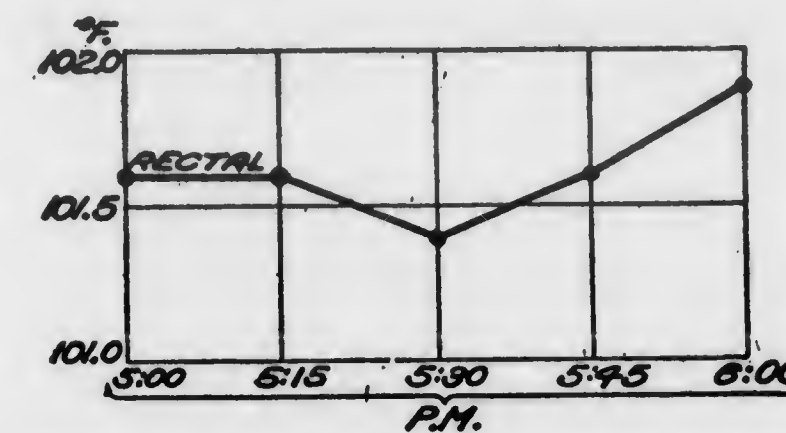


FIG. 25.—Variations in body temperature of cow 886 on January 4, 1920, 5 p. m. to 6 p. m. Cow not fed till 6 p. m.; standing all the time.

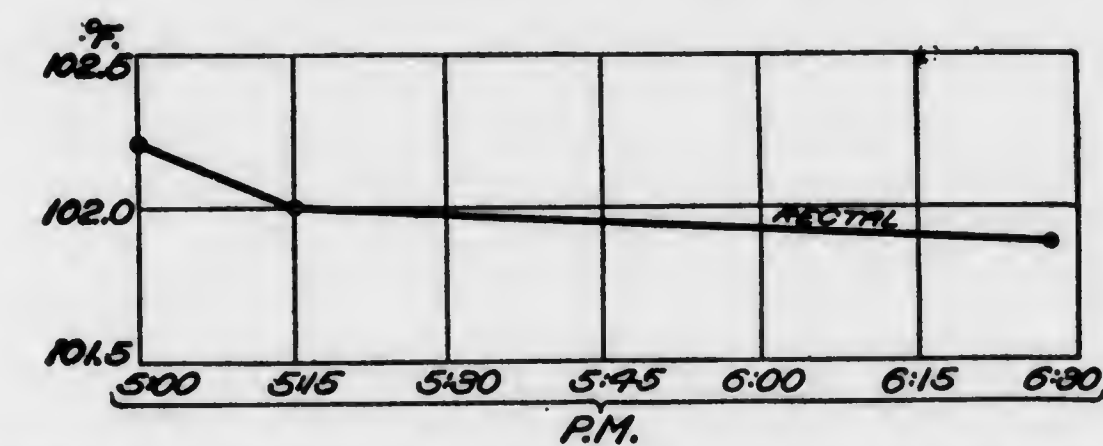


FIG. 26.—Variations in body temperature of cow 886 on March 20, 1920, 5 p. m. to 6.25 p. m. Cow not fed till 6.25 p. m.; standing all the time.

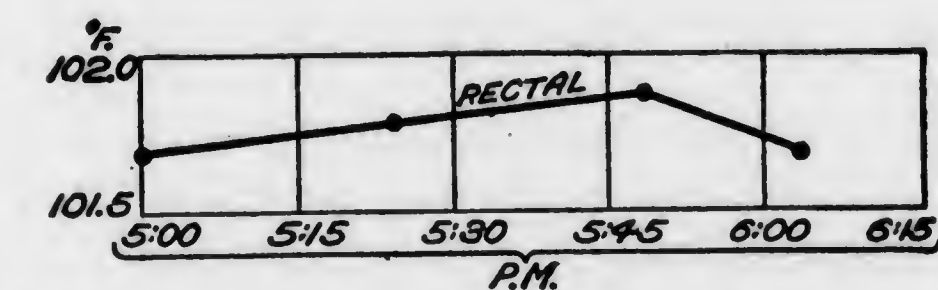


FIG. 27.—Variations in body temperature of cow 885 on January 12, 1920, 5 p. m. to 6.04 p. m. Cow not fed till 6 p. m.; standing all the time.

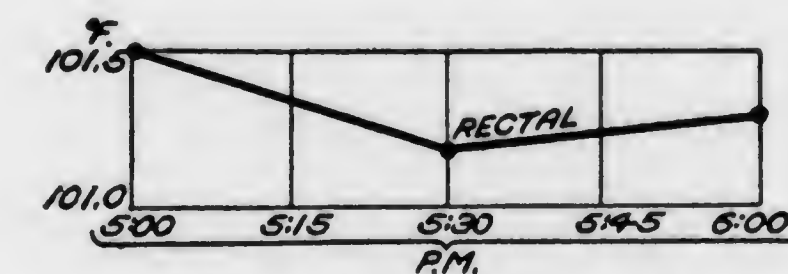


FIG. 28.—Variations in body temperature of cow 885 on February 16, 1920, 5 p. m. to 6 p. m. Cow not fed till 6 p. m.; standing all the time.

The subsequent fall in temperature can be ascribed partly to the fact that the temperature of the feed is lower than that of the body, thus tending to lower somewhat the temperature of the latter, and partly to the natural tendency of the body temperature to drop after a stimulated rise.

The act of defecation did not produce any effect.

The highest rectal temperature obtained during these observations was 102.4° F. (fig. 16), while the lowest was 101.2° (fig. 28). The highest vaginal temperature obtained was 102°, while the lowest was 101.°

The rectal temperature at 6 p. m. fluctuates in all cases, except in one (fig. 28), between 101.5° and 102° F.

OBSERVATIONS ON THE EFFECT OF CHANGE IN POSITION ON BODY TEMPERATURE

It is an established fact that an animal produces more heat when standing than when lying. This being the case, one might, therefore,

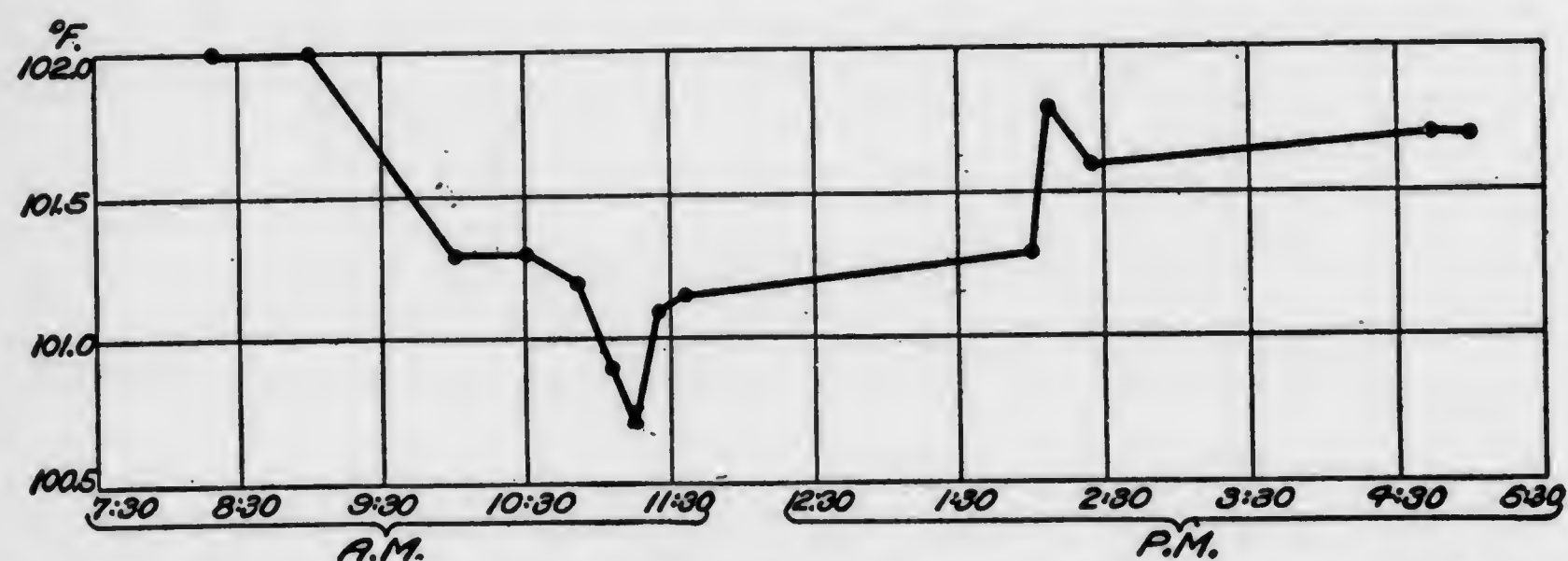


FIG. 29.—Temperature curve of cow 886 for January 5, 1920, 8.20 a. m. to 5 p. m., including effects of change in position. At 8.20 a. m. lying; 8.40 a. m. drank 13.6 kgm. of water at 50° F.; 9 a. m. just lay down; 9 a. m. to 10.30 a. m. lying; 10.31 a. m. forced to get up; 10.50 a. m. immediately before defecating; 10.54 a. m. immediately after defecating; 11.06 a. m. lying since 10.57 a. m.; 11.15 a. m. still lying; 11.24 a. m. up since 11.20 a. m.; 11.36 a. m. still up; 2 p. m. just lay down; 2.02 p. m. forced to get up; 2.06 p. m. up since 2.02 p. m.; 2.24 p. m. down since 2.20 p. m.; 4.45 p. m. down since 4 p. m.; 4.48 p. m. forced to get up; 5 p. m. immediately after defecating.

expect some changes in the temperature of the body when the animal changes its position. Although the position of the animal was noted in the previous observations, the changes were not frequent enough to show any effect. The following observations were made chiefly with the view of studying the possible effects on the body temperature that may arise from a forced or voluntary change in position.

Figure 29 represents observations made on the rectal temperature of cow 886 on January 5, 1920, from 8.20 a. m. to 5 p. m.

The most striking features of the curve are the sudden fluctuations between 10.50 a. m. and 11.24 a. m., and between 2 p. m. and 2.20 p. m. The accelerated fall in temperature (effect of the water) from 10.57 a. m.

to 11.15 a. m. in the former case appear to be due largely to a change from a standing to a lying position, while the subsequent sudden rise at 11.24 a. m. is apparently due largely to the change from a lying to a

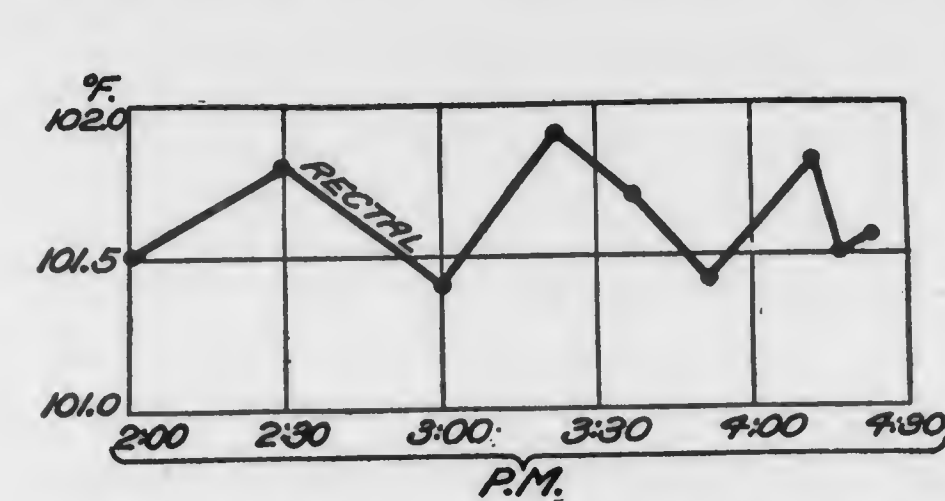


FIG. 30.—Temperature curve of cow 886 for January 13, 1920, 2 p. m. to 4.22 p. m., including effects of change in position. From 2 p. m. to 3.20 p. m. forced to get up; 3.22 p. m. immediately after defecating, urinating with thermometer in rectum; 3.52 p. m. lying since 3.48 p. m.; 4.16 p. m. just got up; 4.22 p. m. still up.

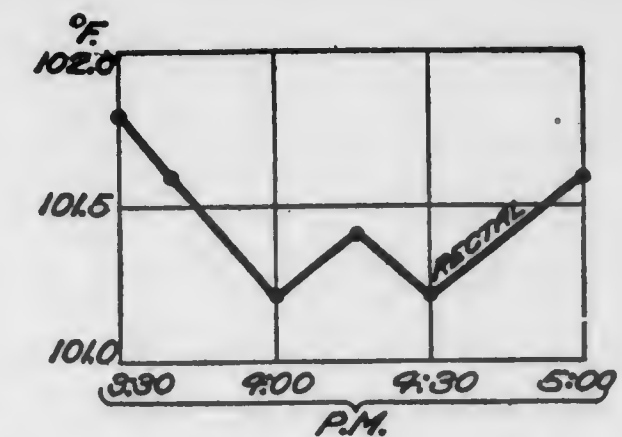


FIG. 31.—Temperature curve of cow 886 for January 15, 1920, 3.30 p. m. to 5 p. m., including effects of change in position. At 3.30 p. m. lying; 3.32 p. m. forced to get up; 3.40 p. m. to 5 p. m. standing; 4.15 p. m. urinated with thermometer in rectum.

standing position. In the second case the sudden rise from 2 p. m. to 2.06 p. m. appears to be due to the change from a lying to a standing position, while the subsequent drop at 2.24 p. m. apparently represents

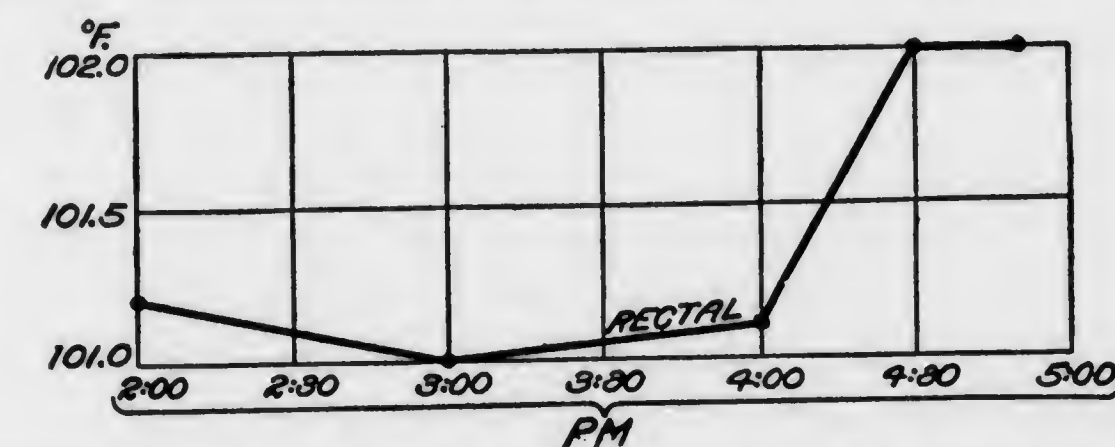


FIG. 32.—Temperature curve of cow 886 on January 30, 1920, 2 p. m. to 4.50 p. m., including effects of change in position. At 2 p. m. lying; 2.43 p. m. to 4.50 p. m. standing.

the effect of the change from the standing to a lying position and also perhaps the tendency for the body temperature to come back to normal. It should be noted that in both cases the effect is not lasting.

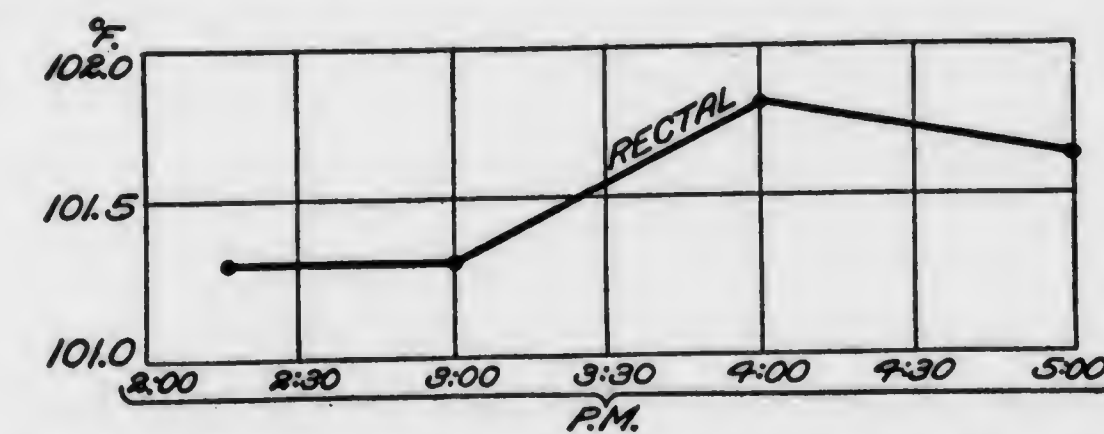


FIG. 33.—Temperature curve of cow 886 on February 16, 1920, 2.15 p. m. to 5 p. m., including effects of position. From 2.15 p. m. to 5 p. m. standing.

A careful study of figures 30 to 35 reveals that, in general, the position of the animal hardly affects the normal course of the fluctuations of its body temperature, for, while the fluctuations were considerable

and rather irregular at the time when the cow did not change her position (fig. 31, 32, 35), the temperature remained fairly uniform when the position was changed (fig. 32 and especially fig. 34).

DAILY VARIATIONS IN BODY TEMPERATURE MEASURED AT 5 P. M.

Inasmuch as at the Institute of Animal Nutrition the determinations of the heat produced by cows by means of the respiration calorimeter are made during a period of 24 or 48 hours, it appears that a knowledge of the daily variations in the body temperature at exactly the same time of the day, corresponding to the beginning and the end of the period, is most essential, as far as those experiments are concerned. That the body temperature of the same animal varies from day to day and from hour to hour has been shown by most of the foregoing observations, even by those made during the time when there was no influence of water or feed (fig. 25-28). To study the extent of the daily fluctuations in body temperature determined at exactly the same time of the day was the object of the next series of observations. To avoid any effect of water drunk or of feed, the observations were made just before feeding at exactly 5 p. m.

Figures 36 to 38 represent the temperatures of cow 886 measured at 5 p. m. for the days there indicated.

All these curves resemble each other very much, showing considerable fluctuations. In figure 36 the lowest temperature is 101.6° F., while the highest is 102.4°. In figure 37 the lowest temperature is 101.4°, while the highest is 102°. In figure 38 the lowest temperature is 101.7°, while the highest is 102.2°.

Figures 39 to 41 represent the temperatures of cow 885 measured at 5 p. m. for the days there indicated.

These three curves resemble each other very much, but they are different from the three preceding curves of cow 886 in that they show much less variation. The lowest temperature in figure 39 is 101.6° F., while the highest is 101.9°. In figure 40 the lowest temperature is 101.8°, while the highest is 101.9°. In figure 41 the lowest temperature is 101.5°, while the highest is 101.8°.

GENERAL CONCLUSIONS WITH REGARD TO THE DAILY VARIATIONS IN TEMPERATURE AT 5 P. M.

The foregoing observations show that daily fluctuations in body temperature depend to a large extent on the individuality of the cow. It is, therefore, not safe to assume in every case that the body temperature of a cow is the same at the same hour of the day, even under normal conditions.

Variations of 0.5° or 0.6° F. in the body temperature of the same animal (886) measured at exactly the same time of the day for several

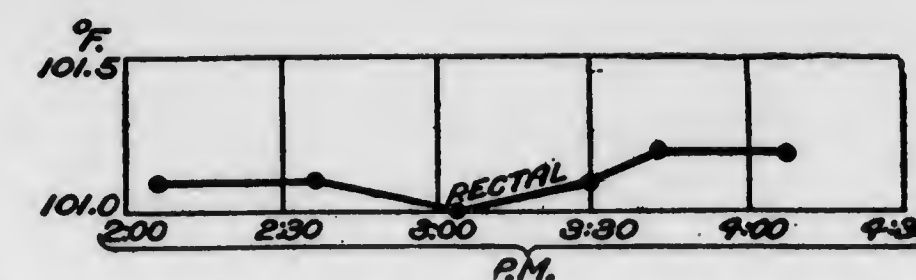


FIG. 34.—Temperature curve of cow 885 for January 13, 1920, 2.06 p. m. to 4.06 p. m., including effects of change in position. At 2.06 p. m. standing; 2.36 p. m. standing; 3.04 p. m. down since 2.48 p. m.; 3.30 p. m. still down; 3.42 p. m. up since 3.38 p. m.; 4.06 p. m. still up.

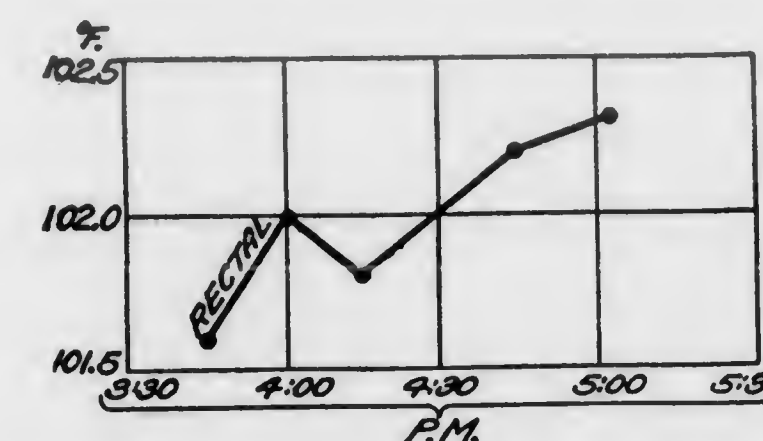


FIG. 35.—Temperature curve of cow 885 for March 22, 1920, 3.45 p. m. to 5.03 p. m., including effects of position. From 3.45 p. m. to 5.03 p. m. standing.

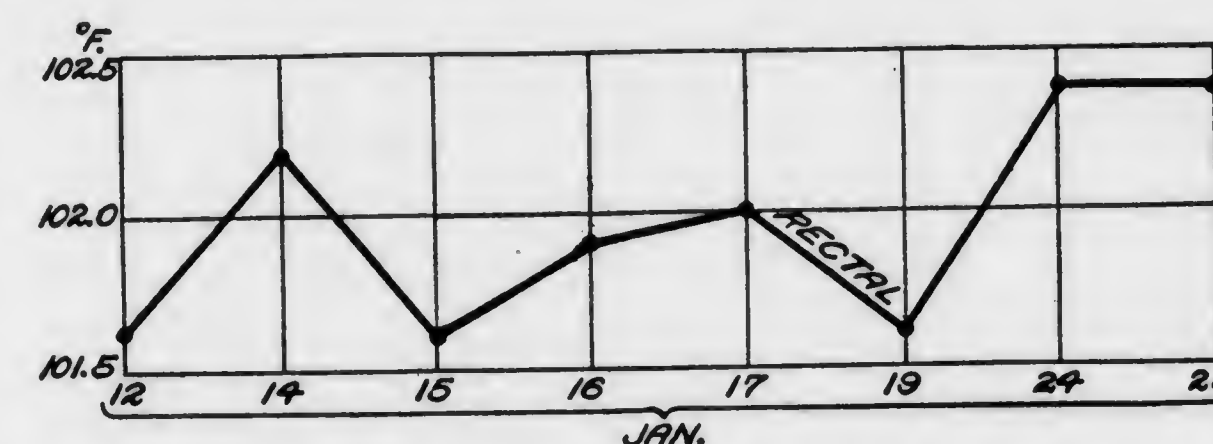


FIG. 36.—Temperature curve of cow 886 for January 12 to January 25, 1920, 5 p. m.

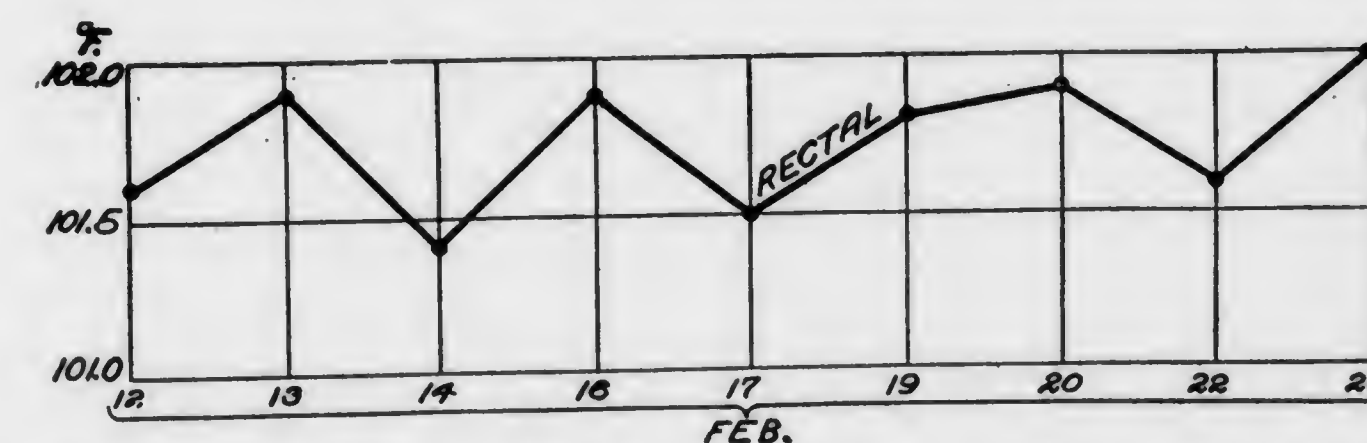


FIG. 37.—Temperature curve of cow 886 for February 12 to February 23, 1920, 5 p. m.

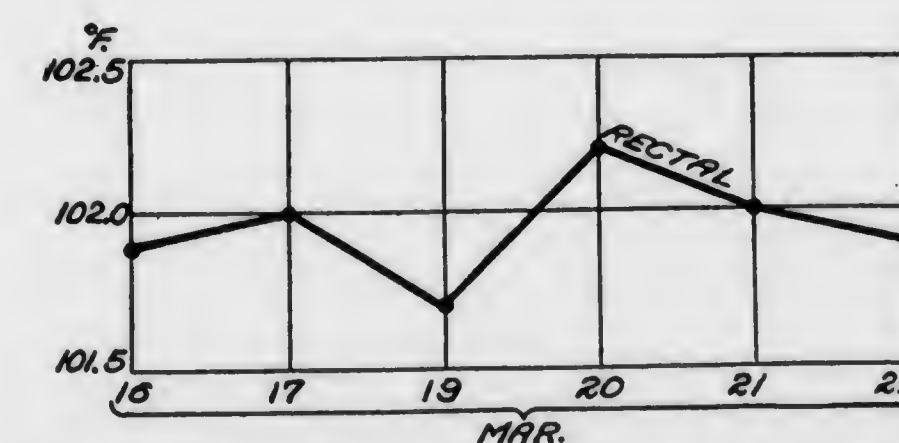


FIG. 38.—Temperature curve of cow 886 for March 16 to March 22, 1920, 5 p. m.

consecutive days are quite common, and greater ones are possible even under identical conditions.

DAILY VARIATIONS IN BODY TEMPERATURE MEASURED AT 8 A. M., 1.30 P. M., AND AT 9 A. M., RESPECTIVELY, FOR SEVERAL CONSECUTIVE DAYS

It has been shown by the very first observations (fig. 1-10) what effect the water drunk under the conditions of the experiment has on

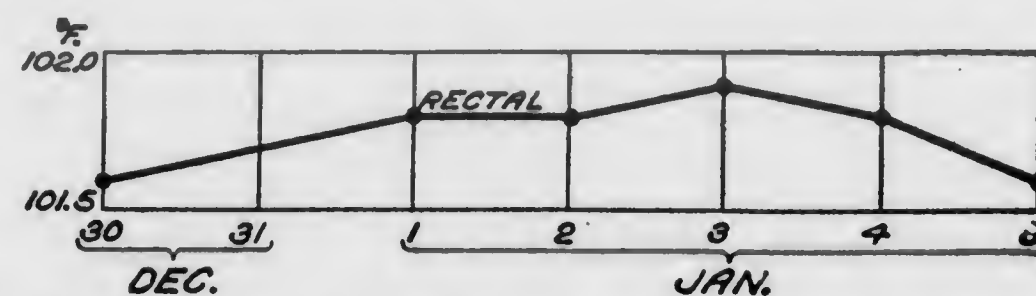


FIG. 39.—Temperature curve of cow 885 for December 30, 1919, to January 5, 1920, 5 p. m.

the body temperature—that if water is drunk in considerable quantity the fall in temperature is very marked, and this effect may last more than three hours, but that after this effect is overcome the temperature

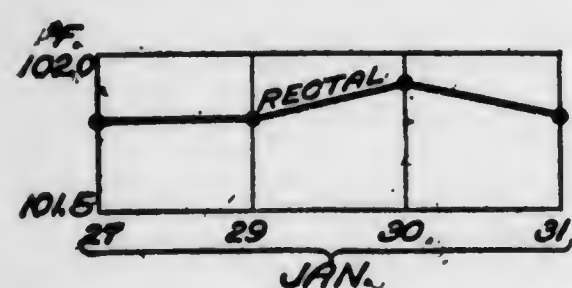


FIG. 40.—Temperature curve of cow 885 for January 27 to January 31, 1920, 5 p. m.

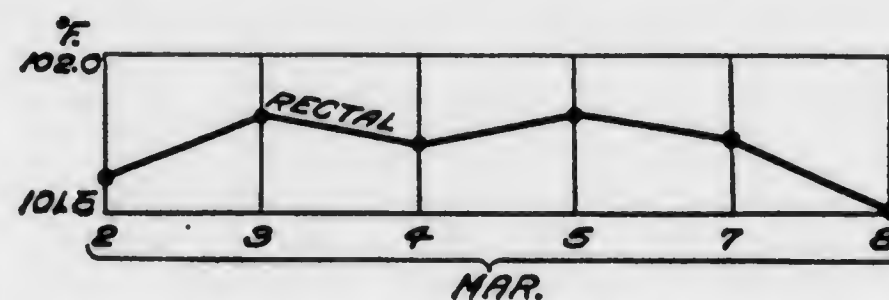


FIG. 41.—Temperature curve of cow 885 for March 2 to March 8, 1920, 5 p. m.

remains quite uniform for about the next three hours. It would therefore perhaps be interesting to see a graphic representation of the temperature changes for several days when measured, first, before watering,

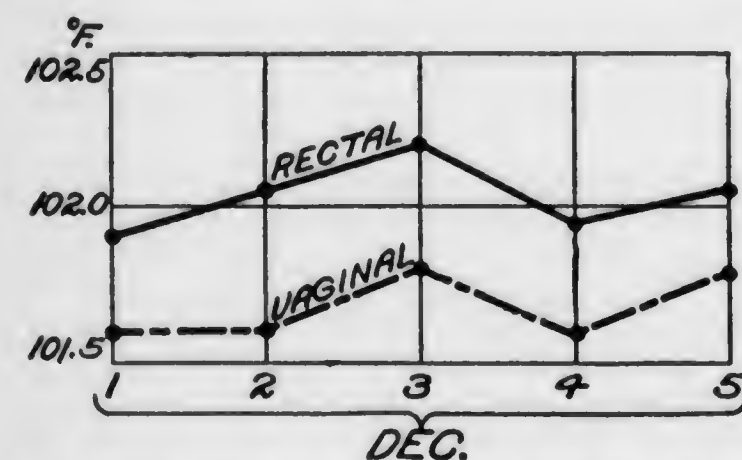


FIG. 42.—Temperature curve of cow 886 for December 1 to December 5, 1919, 8 a. m., before watering.

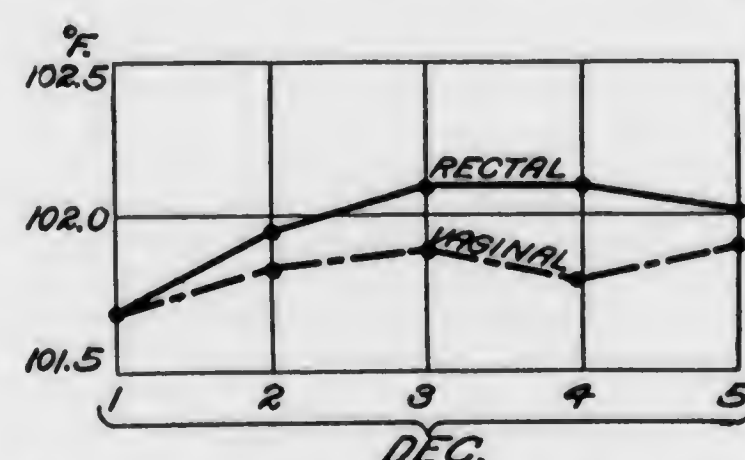


FIG. 43.—Temperature curve of cow 886 for December 1 to December 5, 1919, 1.30 p. m.

second, when the effect of the water has been overcome, and, third, about an hour after watering. Accordingly, the respective temperatures observed during the first few days of the experiment (fig. 1-10), at 8 a. m., at 1.30 p. m., and at 9 a. m., are shown by figures 42 to 46.

Figures 42 and 43 represent the temperatures of cow 886 at 8 a. m. and at 1.30 p. m., respectively, for December 1 to December 5, 1919.

Figures 44 and 45 represent the temperatures of cow 885 at 8 a. m. and at 1.30 p. m., respectively, for December 1 to December 5, 1919. In figure 44 the temperature for December 3 is omitted because the observations did not begin till 8.20 a. m. that day.

On comparing these curves (fig. 42-45) with those obtained at 5 p. m. for the two cows (fig. 36-41) it is observed that while the temperature

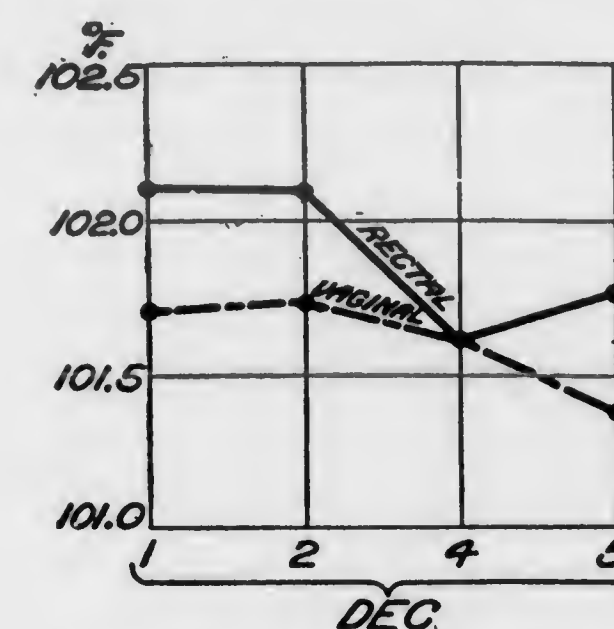


FIG. 44.—Temperature curve of cow 885 for December 1 to December 5, 1919, 8 a. m., before watering.

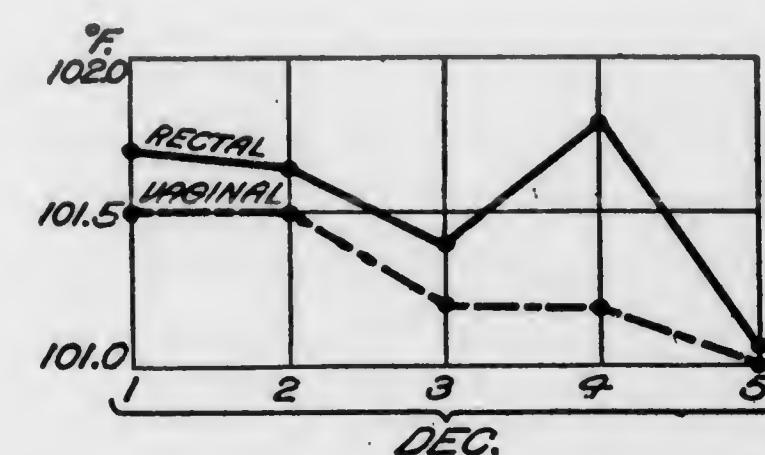


FIG. 45.—Temperature curve of cow 885 for December 1 to December 5, 1919, 1.30 p. m.

of cow 886 at 5 p. m. fluctuated to a large extent from day to day, her body temperature at 8 a. m. or at 1.30 p. m. varied relatively little. On the other hand, the temperature of cow 885, which is very uniform at 5 p. m., varies considerably more at 8 a. m. or at 1.30 p. m. These differ-

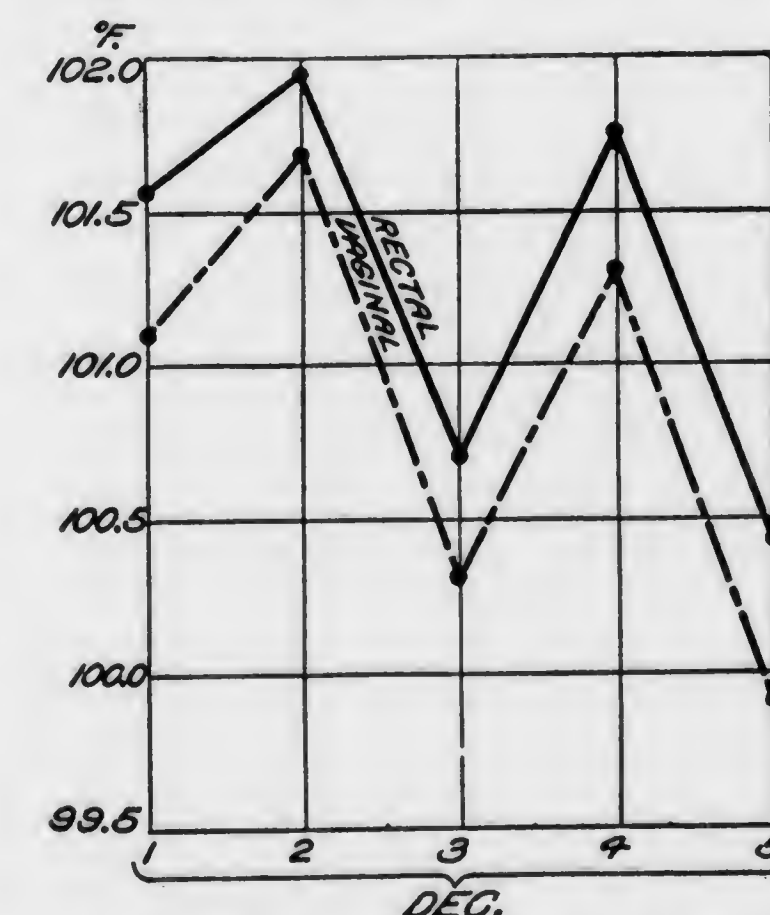


FIG. 46.—Temperature curve of cow 885 for December 1 to December 5, 1919, 9 a. m., showing the effect of water. On December 1 cow drank 29.4 kgm. at 8.30 a. m. On December 2 she refused to drink. On December 3 she drank 22 kgm. at 8.05 a. m. On December 4 she refused to drink. On December 5 she drank 23 kgm. at 8.10 a. m.

ences, apparently due to the individuality of the cow, can not be explained.

Figure 46, representing the temperatures of cow 885 at 9 a. m. for December 1 to December 5, 1919, shows very strikingly the possible

differences in body temperature when measured at exactly the same time of the day but under the influence of the water drunk.

SUMMARY OF RESULTS

The several series of temperature observations on two dry cows lead to the following conclusions:

(1) The rectal temperature is higher than the vaginal when measured at the same depth of 7 inches, showing an average excess of about 0.3° F. The relative values, however, vary under different conditions but show a trend toward parallelism.

(2) A fall in temperature invariably follows the drinking of water. This fall varies directly with the quantity of water drunk. After the effect of the water drunk in the morning has been overcome, the temperature remains fairly constant till about 2.30 p. m. When no water is drunk, the temperature is practically constant in the morning and in the afternoon till about 2.30 p. m.

(3) There is a gradual rise in temperature in the afternoon from about 2.30 p. m. to about 5 p. m.

(4) Eating of feed raises the body temperature slightly for about $\frac{1}{2}$ hour when the cows receive a maintenance ration.

(5) The temperature of the rectum or vagina is decidedly higher when measured as a depth of 6 or 7 inches than at a depth of 4 or 5 inches, thus indicating a temperature gradient.

(6) There is no material change in temperature between a depth of 6 inches and a depth of 7 inches, whereas there is a distinct difference in temperature between a depth of 4 inches and a depth of 6 inches, thus showing the unreliability of measuring the temperature at a depth of less than 6 inches.

(7) The position of the animal has hardly any effect on the body temperature, but there is some indication that the temperature is slightly affected when measured shortly after the change in position has been made (fig. 29).

(8) There is no difference in temperature when measured before or after defecation.

(9) Daily fluctuations in body temperature depend to a great extent on the individuality of the cow.

(10) A variation of 0.8° F. in the rectal temperature of the same animal was observed, when measured at the same time of the day under identical conditions and outside the influence of water or feed (fig. 36), while under the influence of water a difference of 1.3° was observed in two consecutive days measured at the same time of the day (fig. 46).

OBSERVATIONS ON THE BODY TEMPERATURE OF DRY COWS

By MAX KRISS

INSTITUTE OF ANIMAL NUTRITION, THE PENNSYLVANIA STATE COLLEGE

Communicated by H. P. Armsby, August 20, 1920

While a knowledge of the normal fluctuations in the body temperature of cattle is of importance to the veterinarian insofar as it may help to detect diseased conditions, it assumes special significance when metabolism experiments on cattle are made with the respiration calorimeter. By means of the latter, the heat eliminated by the animal during a certain period of time, as well as the gaseous exchange between the animal and the atmosphere that surrounds it, is measured. But in order to determine accurately the heat production as distinguished from the heat elimination a correction must be applied for any storage or loss of heat by the animal body and failure to do so might introduce an appreciable error. For example, if at the end of an experimental period the body temperature of an animal weighing 400 kilograms differs by 1° C. from that at the beginning, it means a storage or loss of heat by the body amounting to 332 calories (assuming the specific heat of the body to be 0.83). The data on record regarding the body temperature of farm animals are unsatisfactory for the reason that the observations have not been repeated often enough under different conditions which are known to affect the temperature of man. In this investigation an attempt has been made to secure data regarding the extent and the course of the body temperature variations in cattle and to study some of the factors that might influence them. The investigation covers a period of some sixteen weeks. The animals were two dry cows used at the same time for metabolism experiments with the respiration calorimeter, in which strict control of feeding, environment, etc., is maintained. Several series of observations on the body temperature of the cows have been made with special reference to the study of the following:

- (1) Variations in body temperature from about 7.30 a. m. to about 5.30 p. m., including the effect of water drunk.
- (2) Thermal gradient in the body.
- (3) Variations in body temperature from about 5 p. m. to about 7 p. m., including the effect of the feed.

(4) Effect of the act of defecation and of change in position.

(5) Daily variations in body temperature measured at exactly the same hour of the day.

The observations were made by means of carefully standardized clinical thermometers. During the greater part of the experiment one and the same thermometer was used, while for simultaneous readings of the rectal and vaginal temperatures a second one was used. To avoid any possible error that might be due to the use of two different thermometers, the latter were for a few days interchanged, i.e., the thermometer used one day for measuring the rectal temperature was used the following day for the vaginal and vice versa. This was further checked by using one and the same thermometer for both the rectal and vaginal temperature readings being taken one immediately after the other.

The observations on the thermal gradient were made at a depth of 4, 5, 6, and 7 inches. All other observations were made at a depth of 7 inches. The thermometers, which were originally five inches long, were accordingly lengthened by means of a piece of rubber tubing slipped a half inch or so over the upper end of the thermometer and over the string attached to the loop and stiffened by inserting inside the rubber tubing a strip of copper wire. This added portion was finally covered with adhesive plaster and a rubber ring tightly fitted at the end. This arrangement proved to be very satisfactory. The thermometer could be inserted to the desired depth and there was little danger of breaking it during the insertion. The thermometer was ordinarily allowed to stay in the rectum or vagina for about three minutes and the time and temperature recorded immediately upon its removal.

The results of the several series of observations may be summarized as follows:

(1) The rectal temperature was higher than the vaginal when measured at the same depth of 7 inches, showing an average excess of about 0.3° F. The relative values, however, varied under different conditions, but showed a trend toward parallelism.

(2) A fall in body temperature invariably followed the drinking of water. This fall varied directly with the quantity of water drunk. After the effect of the water drunk in the morning had been overcome, the temperature remained fairly constant till about 2.30 p. m. When no water was drunk the temperature was practically constant in the morning and in the afternoon till about 2.30 p. m.

(3) There was a gradual rise in temperature in the afternoon from about 2.30 p. m. to about 5.00 p. m.

(4) Eating of feed raised the body temperature slightly for about a half hour when the cows received a maintenance ration.

(5) The temperature of the rectum or vagina was decidedly higher when measured at a depth of 6 or 7 inches, than at a depth of 4 or 5 inches.

(6) There was no material difference in temperature between a depth of 6 inches and one of 7 inches, while there was a distinct difference of temperature between a depth of 4 inches and one of 6 inches, thus showing the unreliability of measurements of temperature at a depth of less than 6 inches.

(7) The standing as compared with the lying position of the animal had hardly any effect on the body temperature, but there was some indication that the temperature was slightly affected when measured shortly after the change in position had been made.

(8) There was no difference in body temperature when measured before or after defecation.

(9) Daily fluctuations in body temperature depend to a great extent on the individuality of the cow.

(10) A variation of 0.8° F. in the rectal temperature of the same animal was observed, when measured at the same hour of the day under identical conditions and outside the influence of water or feed, while under the influence of water a difference of 1.3° F. was observed at the same hour on two consecutive days.

A detailed report of the results will appear in the *Journal of Agricultural Research*.

THE INFLUENCE OF POTASSIUM PERMANGANATE ON KJELDAHL NITROGEN DETERMINATIONS

By Donald C. Cochrane

INSTITUTE OF ANIMAL NUTRITION, PENNSYLVANIA STATE COLLEGE, STATE
COLLEGE, PA.

Received August 17, 1920

In a paper read before the Association of Official Agricultural Chemists at the meeting of November 1915, Frear questioned the accuracy of the Kjeldahl method for nitrogen as commonly used in fertilizer analysis. The data which Frear presented showed that a large loss of nitrogen occurred in determinations on fertilizers when potassium permanganate was added; that the time elapsing between cessation of boiling and the addition of the permanganate influenced the results; and that the presence or absence of nitrates made no appreciable difference in the loss occurring on the addition of the permanganate.

It was therefore deemed advisable to check the method upon substances commonly met with in nutrition work, paying particular attention to the influence on the results of the addition or non-addition of potassium permanganate.

TECHNIQUE

METHOD 1. WITH POTASSIUM PERMANGANATE—Weigh by difference from a glass-stoppered weighing bottle directly into a 300-cc. Kjeldahl digestion flask about 1 g. of substance, and add 0.3 g. of metallic mercury and 30 cc. of concentrated sulfuric acid, rotating the flask during the addition of the acid in order to wash down any particles of the sample adhering to the neck of the flask. Heat cautiously over the naked flame of a Bunsen burner until frothing has ceased, then increase the temperature until vigorous boiling commences, and maintain at this temperature until the solution becomes colorless, and for one hour thereafter. The flask should be shaken occasionally during digestion, which will require a total of about 2.5 hrs. Next, remove the flask from the flame and add in small portions sufficient potassium permanganate to produce a constant pink or green color. If the permanganate is too finely powdered flashing will occur with a resultant loss of nitrogen. About 50 mesh permanganate gives the best results. It is important that the per-

manganate be added immediately after removing the flask from the flame, not more than 10 sec. elapsing between the turning out of the flame and the completion of the addition of the permanganate. Allow to cool, dilute with 200 cc. of water, let stand 15 min.; and transfer from the Kjeldahl flask to an Armsby copper pot containing 25 cc. of potassium sulfide solution (40 g. per liter), washing the flask with 250 cc. of water in three portions. Make strongly alkaline with saturated sodium hydroxide solution, inclining the pot so that the hydroxide will flow to the bottom without mixing, and connect at once with the distillation apparatus. Shake vigorously to insure thorough mixing. Collect the ammonia in standard sulfuric acid and complete the titration in the usual manner.

It is of the utmost importance that the delivery tube dip into the standard acid until the first rush of ammonia is over; also that the standard acid be stirred frequently in order to prevent the lighter ammonia-carrying distillate from collecting on the top, thus causing loss of ammonia.

METHOD 2. WITHOUT POTASSIUM PERMANGANATE—The manipulation in this method is identical with Method 1, except that the permanganate is omitted.

DISCUSSION

The results of nitrogen determinations on twenty-four samples are shown in Table I. The time of digestion in both methods was the same for each sample. Blanks were run on each lot of reagents and the nitrogen results were corrected for the blanks.

In every case except one (Oat Straw A) the average percentage of nitrogen is lower where permanganate was not added. The allowable difference between extremes on triplicate nitrogen determinations on feeds and feces in these laboratories is 0.05 per cent. In this series, however, all determinations are taken into consideration. Attention is directed to the wide variations between extremes where the permanganate was omitted.

It is a well-recognized fact that a loss of nitrogen occurs where flashing results from the addition of permanganate. If a loss of nitrogen occurs, as is stated by numerous authorities,¹ on addition of the manganate even where flashing does not ensue, it is possible that the result obtained is in reality a

¹ Z. anal. Chem., 22, 375; 57, 524; 69, 439.

TABLE I

Substance	No. of Deter- mina- tions	Average	Method 1 ¹ Nitrogen (Per cent)				No. of Deter- mina- tions	Average	Method 2 ² Nitrogen Per cent				Diff. between Method 1 and Method 2			
			Individual Variations (from Average)		Diff. between Individual Extremes				Individual Variations (from Average)		Diff. between Individual Extremes					
			Low	High					Low	High						
Alfalfa Hay A.....	4	2.505	0.007	0.006	0.013		6	2.420	0.030	0.045	0.075		-0.085			
Alfalfa Hay B.....	3	2.380	0.011	0.010	0.021		3	2.293	0.067	0.015	0.082		-0.087			
Alfalfa Hay C.....	3	2.388	0.038	0.020	0.052		5	2.385	0.036	0.029	0.065		-0.003			
Alfalfa Hay D.....	3	2.394	0.009	0.011	0.020		4	2.383	0.026	0.021	0.047		-0.011			
Alfalfa Hay E.....	3	2.448	0.016	0.016	0.032		3	2.359	0.035	0.041	0.076		-0.089			
Oat Straw A.....	3	0.445	0.009	0.008	0.017		3	0.455	0.005	0.010	0.010		+0.010			
Oat Straw B.....	3	0.528	0.019	0.009	0.028		3	0.486	0.003	0.002	0.005		-0.042			
Oat Straw C.....	3	0.494	0.003	0.002	0.005		3	0.488	0.007	0.004	0.011		-0.006			
Ref. Feed A.....	2	2.043	0.008	0.008	0.016		2	2.004	0.073	0.072	0.145		-0.039			
Ref. Feed B.....	2	2.329	0.008	0.011	0.019		3	2.321	0.065	0.045	0.110		-0.008			
Mixed Grain A.....	3	2.712	0.021	0.020	0.041		3	2.623	0.099	0.074	0.173		-0.089			
Mixed Grain B.....	4	2.714	0.019	0.027	0.046		4	2.663	0.122	0.058	0.180		-0.092			
Mixed Grain C.....	3	2.755	0.022	0.022	0.045		4	2.639	0.036	0.022	0.058		-0.076			
Mixed Grain D.....	4	2.727	0.027	0.040	0.067		4	2.678	0.047	0.026	0.073		-0.049			
Corn Meal A.....	3	1.555	0.013	0.006	0.019		3	1.503	0.076	0.043	0.119		-0.052			
Linseed Meal A.....	3	6.354	0.013	0.015	0.028		3	6.281	0.026	0.014	0.040		-0.073			
Linseed Meal B.....	3	6.375	0.023	0.040	0.063		3	6.256	0.010	0.006	0.016		-0.119			
Peanut Meal A.....	3	2.999	0.025	0.028	0.053		3	2.725	0.040	0.034	0.074		-0.074			
Comp. Feces A.....	3	3.024	0.029	0.022	0.051		3	2.966	0.029	0.034	0.063		-0.058			
Comp. Feces B.....	3	2.563	0.022	0.007	0.031		3	2.448	0.061	0.061	0.122		-0.115			
Comp. Feces C.....	3	2.499	0.010	0.010	0.020		3	2.474	0.006	0.008	0.014		-0.025			
Comp. Feces D.....	3	2.413	0.011	0.010	0.021		3	2.344	0.010	0.014	0.024		-0.069			
Comp. Feces E.....	3	2.281	0.018	0.019	0.037		3	2.219	0.024	0.021	0.045		-0.062			
Comp. Feces F.....	3	2.163	0.017	0.018	0.035		3	2.109	0.021	0.017	0.038		-0.054			

¹ Average blank on reagents 0.81 mg. N.

² Average nitrogen per sample 25.92 mg.

³ Sample very poorly ground.

balance figure representing compensation between a loss due to the permanganate and a gain through a more effective oxidation of the organic matter through the addition. Assuming such to be the case, the discrepancy between the conclusions drawn from determinations on this class of substances and the work reported by Frear on fertilizers may be explained. The possible presence of cyclic compounds containing nitrogen in the ring should not be overlooked.¹

There is a wide difference of opinion among analysts as to the proper interpretation of "immediately" as used by Kjeldahl² in his original description of the method. It was found to be impossible with the equipment at hand to determine the rate of cooling of the sulfuric acid solution after removal of the flame. However, a series of determinations was made in which the variant was the time elapsing between cessation of boiling and the addition of permanganate. Ten seconds was found to be the minimum time required to turn off the gas, remove the flask, and add the permanganate.

SUBSTANCE	KMnO ₄ Added		No KMnO ₄ Nitrogen Per cent
	10 Sec. Nitrogen ¹ Per cent	2 Min. Nitrogen Per cent	
Alfalfa Hay	2.422	2.379	2.311
Alfalfa Hay	2.458	2.448	2.397
Mixed Grain	2.755	2.732	2.643
Feces	2.499	2.475	2.439

¹ All nitrogen results are the average of three determinations.

Here again the results obtained are decidedly in favor of the permanganate. No tendency to flash was apparent after 2 min. Hence it would seem that if flashing is dependent on temperature the critical point must be between 10 sec. and 2 min. after cessation of boiling.

CONCLUSIONS

1—The claim that the addition of permanganate in the Kjeldahl method causes loss of nitrogen is not substantiated by the results obtained on feeds and feces.

2—Nitrogen determinations made without the addition of permanganate on feeding stuffs and feces are less concordant, and are uniformly lower than those in which permanganate is used.

¹ *J. Biol. Chem.*, **17**, 275.

² *Z. physiol. Chem.*, **57**, 516; **69**, 439.

THE RESPIRATORY QUOTIENT AND ITS UNCERTAINTY

J. A. FRIES

From the Institute of Animal Nutrition, State College, Pa.

Received for publication September 9, 1920

The common definition of the respiratory quotient, i.e., the ratio of the volume of the CO₂ produced to the volume of O₂ consumed $\frac{(\text{CO}_2)}{(\text{O}_2)}$, is the correct expression when applied to the gas exchange which takes place when a definite substance or mixture is completely oxidized, but appears wholly inadequate when its application is to include the gas exchange of all living organisms or animals. Upon the definition or interpretation of the term will also naturally depend what method may be used in the determination of the respiratory quotient. If we understand the term "respiratory quotient" to apply to the collective exchange of gases due to the metabolic activity of the individual cells forming the body tissues of an animal, then the method for its determination must necessarily be such as to be able to meet the requirements arising because of the nature and complexity of the animal body.

Sources of error. Even among animals of the higher order, like man, having a comparatively simple digestive tract as compared with cattle where the digestive tract is more complex, there is a great difference in the volume, composition and origin of the gases eliminated. Gases from outside and unknown sources may therefore mask the respiratory quotient if the total exchange of gases is the only thing determined. Further, while the total respiratory exchanges for consecutive whole days may show uniformity, through each day there may be periods which differ widely one from another.

Work on human subjects. To illustrate the extent of such variation the author wishes to refer to the elaborate, very complete and valuable metabolism experiments, by means of a closed circuit respiration calorimeter on man with and without food, by F. G. Benedict (1).

From the number of experiments recorded we select and refer to but two of the longer ones—experiments 75 and 76. The first of these

was a fasting experiment, the man remaining in the respiration calorimeter for seven days without food and moving about [as little as possible. This was immediately followed by another period of three days in the respiration calorimeter with food, as the second experiment, so that the subject was in the chamber for ten consecutive days. During these experiments the composition of the total ingo and outgo of solids, liquids and gases was determined. The CO_2 production was determined during the entire time for each two hours by absorbing it in soda lime and weighing the amount. Oxygen was supplied from a cylinder which was weighed from time to time, and besides, once each day, the residual air was sampled and the oxygen determined by absorption by potassium pyrogallate. From these weights and determinations together with other data the amount of oxygen consumed during each 2-hour period was computed.

For the seven fasting days the daily 24-hour respiratory quotients agree very well, the average being 0.75, and for the following three days with food the average was 0.817. With the 2-hour periods, however, it is different, for in these we find between the lowest and highest respiratory quotient during the day a difference ranging from 18.84 per cent on one day to as much as 91.83 per cent on another. Stating it differently, the greatest difference between a 2-hour period and the average for the same day was 37.18 per cent. From this we see that if a few small periods should be taken to represent the day, the result may be far from the real average. This is but one of the many lessons we may learn from the valuable experiments referred to.

Again the author wishes to refer to work done at the Carnegie Institution Nutrition Laboratory, Boston, Mass. (2).

To secure the respiratory products in connection with these comparative tests several different methods were used including nose and mouth pieces, masks and bed calorimeter, and the determinations of the gases were made by means of various gas analysis apparatus. The results of a very large number of tests are given. A test period, i.e., the time during which a sample was taken, was usually about 15 minutes except with the bed calorimeter where the periods were 45 minutes. Two to several such short periods taken alternately by the two methods to be compared were grouped together and the averages of such experimental groups are used in comparing the methods.

All these different methods and tests seem to have one thing in common, namely, between successive tests variations in the respiratory quotients obtained were noticed which frequently were quite large.

It is noticed that in about sixty of these groups of tests there was a difference of over 9 per cent between two successive tests or two of the tests within the group, the differences ranging as high as 31.4 per cent between two of the tests in a group. Tests made on the same subject on successive days under similar conditions using the same method of determination, gave respiratory quotients, for the same time of the day, which varied as much as 11.1 to 18.2 per cent for two of three subjects on which such comparisons were obtainable. These tests were made under as ideal conditions as possible for such comparative work and hence we should not expect so much difference.

The frequency of pulse and respiration was given in nearly all cases, but since there does not seem to be any uniform corresponding variation in the pulse and respiration to account for these well distributed differences in the gas exchange, they may, partly at least, be due to causes outside the body tissue. These variations, however, bear out what was said before; that a few short periods can not be relied upon to represent a whole day.

One point to which the author wishes to call attention is that with an animal body, like the human body for instance, we do not deal solely with a complex single unit, but at the same time with the results of the activity of a numberless host of enemies or friends in the form of individuals, mostly microscopic organisms, living within the body yet not part of it.

In man the gases produced by these organisms will vary according to the physical condition of the body as well as the character of the food eaten. Much of the gas produced in the stomach will by means of eructation pass through the mouth and nose whereas that formed in the intestine no doubt will chiefly follow the course of the feces.

In fasting man such gas production would naturally be reduced to a minimum, though not necessarily ceasing altogether, and while some of the variations referred to may be due to the influence of such fermentation gases it is questionable whether, in the case of fasting men, all the variations can be ascribed to that cause. The respiratory quotient obtained on fasting subjects may, because of the variation of such gases, not be wholly applicable to subjects in different states of health and nutrition. Although the total amount of fermentation gases in man is not very large when compared with some other animals, we know that the rectal gases contain considerable CO_2 as well as CH_4 . Besides the gases which may pass directly from the stomach to the expired air an unknown quantity of CO_2 undoubtedly is absorbed from the intestinal tract and leaves the body by the way of the lung.

Work on ruminants. In the case of ruminants the determination of the respiratory quotient is influenced to a very much larger degree by the fermentation gases than with man, for here one-tenth and more of the total CO₂ produced in the body may come from the paunch and intestinal fermentation. Further these 200 to 300 and more liters of CH₄ production per day is a volume large enough to introduce an error in a respiration experiment unless taken account of.

Much work has been done on the respiratory exchange in cattle by the use of respiration chambers but the writer will only refer to the later work of two or three investigators.

W. Klein (3) gives the results of a number of experiments on oxen carried out with the aid of a respiration chamber of the Regnault-Reiset type.

Below is found the result of eight 24-hour experiments with oxen on varying rations using the Regnault-Reiset method.

TABLE 1
Twenty-four hour respiration experiments with oxen

NUMBER	FEED			O ₂ USED	CO ₂ PRO- DUCED	CH ₄ PRO- DUCED	RESPIRA- TORY QUOTIENT	PAGE
	Hay	Chop	Linseed meal					
	kgm.	kgm.	kgm.	liters	liters	liters		
1	1.5	2.5		2406.0	2371.7	127.0	0.980	203
2	1.5	2.5		2576.4	2407.5	117.0	0.940	204
3	5.0	1.5	1.0	3068.0	2863.0	228.2	0.933	245
4	5.0	1.5	1.0	3021.0	3142.0	244.0	1.040	243
5	5.0	2.0		2606.0	2832.4	158.4	1.087	201
6	5.0	1.0		2610.0	2760.0	146.3	1.057	205
7	8.0	1.5	1.0	3454.0	3548.0	237.0	1.027	241
8	7.0	2.0	25.0*	3727.0	3966.0	316.5	1.064	221
Average of last six				3081.0	3185.2	221.7	1.034	
Average of last five							1.055	

* Beets.

Omitting the first two experiments with the low ration the average respiratory quotient of the other six = 1.034 and the average of the last five = 1.055. These high respiratory quotients obtained during 24-hour experiments by the above method point to something abnormal when we consider the nature and quantity of the food eaten.

Pulmonary respiratory quotient of cattle. To obtain the quotient of the pulmonary respiratory exchange thirty-two short period experi-

ments of 5 to 23 minutes each were conducted as follows: An ox fed the same daily ration at regular hours was placed in the respiration chamber together with his keeper at varying periods during a number of days. The animal had a cannula fitted into the trachea and by means of a tube was in communication with the outside of the chamber and thus breathed the outside air. Usually several of the respiratory experiments constituting a daily period followed closely upon each other, these daily periods changing so that they would cover and represent the positions and activity of the animal for the whole day.

The tests, made under similar conditions in reference to position and activity of the animal, were grouped together in seven groups, and the average respiratory quotients of these seven groups were 0.816; 0.901; 0.814; 0.849; 0.848; 0.882; 1.003; a difference between the lowest and the highest of 23.2 per cent.

Between the individual experiments making up the groups there was a range of from 0.862 to 0.970 = 12.5 per cent in one, 0.784 to 0.866 = 10.4 per cent in another, and from 0.850 to 0.972 = 14.3 per cent in a third. The greatest difference between any of the tests representing the day was 0.774 to 1.020 = 31.8 per cent. These figures show how great the variation may be in the gas exchange through the lungs with an animal under normal rest conditions and shows again the uncertainty of short period tests. The average of all the tests representing the day was 0.882.

Thus between the average respiratory quotient, i.e., 1.034 obtained with the Regnault-Reiset method and that of the pulmonary breathing, is a difference of 0.152 = 14.7 per cent which is equivalent to 369 liters CO₂. This represents CO₂ which in one way or another escaped from the intestinal tract of the animal. To test this point experimentally Klein made three short experiments of 125, 132 and 119 minutes respectively by placing the animal in the respiration chamber but caused him to breathe outside air by means of a cannula in the trachea, the fermentation products being allowed to accumulate in the chamber. Short respiration tests were made of the pulmonary gas exchange and the residual gases of the chamber were analyzed at the beginning and end of each experiment with the results shown in table 2.

From these short-period experiments the computed CH₄ per day was 150.6 liters. Klein considers this too small a volume and estimates, basing it upon results of other work, that it should have been at least 250 liters. This difference may be due partly to the short experiments,

TABLE 2

Short pulmonary respiration tests

DATE	RESPIRATION PER MINUTE		COMPUTED TO 24 HOURS				
	O ₂ used	CO ₂ produced	O ₂ used	CO ₂ produced	Respiratory quotient	CO ₂ in chamber	CH ₄ in chamber
	cc.	cc.	liters	liters		liters	liters
6/27/11	2275.5	1972.0	3276.7	2839.7	0.867	393.3	144.0
7/ 4/11	2322.2	1975.0	3344.0	2844.0	0.850	379.0	
7/13/11	2481.7	1908.0	3573.6	2747.5	0.769	411.4	157.3
	2468.2	2140.0	3554.2	3081.6	0.867		
Average.....			3394.9	2866.1	0.845	394.5	150.6

covering perhaps periods of the day of abnormally low fermentation, or else to an excretion of the gases through the lungs. CH₄ having a solubility coefficient equal to 0.035 at 20°C., which is higher than that of O₂, must therefore be absorbed to some extent as well as CO₂ from the paunch where these gases are present in such high percentage. The ratio of CH₄ to CO₂ as found in the above tests was 1:2.62, and therefore the CO₂ corresponding to 250 liters CH₄ would be 655 liters.

On the assumption that the lacking 100 liters CH₄ together with CO₂ at the same ratio as these gases were found in the chamber were excreted through the lungs, then 260.5 liters CO₂ must be subtracted from the pulmonary exchange, and thus the respiratory quotient will be reduced to 0.770. Assuming the other extreme that the lacking 100 liters CH₄ and the corresponding CO₂ were held back or produced after the experiments, then the CO₂ in the chamber should be 654.8 liters for 24 hours. Adding this to the pulmonary CO₂ would raise the respiratory quotient of total gas exchange to 1.037.

That the absorption of CO₂ from the paunch must be much greater than that of CH₄ is self-evident, judging from the very high solubility of CO₂, but the actual amounts of CH₄ and CO₂ which are absorbed from the paunch and the rest of the intestinal tract and pass through the lungs have not been determined.

Ratio of CH₄ to CO₂ in fermentation tests. Markoff (4) has tried to establish experimentally the relation of CH₄ to CO₂ due to fermentation in the paunch and other parts of the intestinal tract of ruminants, by removing some of the content of the various organs and studying the fermentation processes of it while outside the animal body and

gives (4, p. 38) as an average of several very discordant experiments a ratio for CH₄ to CO₂ produced in the paunch of 1:5.19. Gas taken directly from the paunch and analyzed gave (4, p. 2) a ratio of CH₄ to CO₂ of 1:3.68. Thus the difference between 5.19 and 3.68 or 1.51 would represent CO₂ absorbed into the blood. But if CH₄ is also absorbed then the volume of CO₂ passing through the lungs would also be correspondingly larger and the pulmonary respiratory quotient would be lowered accordingly. Applying these ratios to the average respiratory quotient of Klein's six Regnault-Reiset experiments, assuming that no CH₄ was absorbed and lost, the respiratory quotient 1.034 of the total gas exchange will be changed to pulmonary exchange of the following very low values:

With CH₄ to CO₂ = 1:3.68 respiratory quotient 1.034 = 0.768 corrected
 With CH₄ to CO₂ = 1:5.19 respiratory quotient 1.034 = 0.660 corrected

Elaborate respiration experiments of 24 to 48 hours duration with a milking cow, breathing through a cannula placed in the trachea, have been made by Holger Mollgaard and A. C. Anderson (5). The incision and insertion of the cannula in the trachea was made in such fashion that in a few weeks the sore was healed and the metal inclosed air tight in the natural tissue, thus permitting the use of the cannula uninterruptedly for weeks at a time without any inconvenience to the animal. These long respiration experiments with cattle are a great improvement over the shorter ones of Klein.

The results are given of one such experiment on a milking cow including two 48-hour respiration tests, during which time the pulmonary gas exchange was determined as well as the CH₄ and CO₂ fermentation products which were accumulating in the respiration chamber.

For the oxygen determinations a new method was used which consists in burning the oxygen to H₂O in a hydrogen flame. While the method is not recommended for short periods the inventors claim that for large samples and long continuous periods it has proved very satisfactory. The air in the chamber was sampled at the beginning and end of a period and the gas analyses made on a Bohr-Tobiesen gas analysis apparatus. The pulmonary respiratory exchange for 24 hours was (5, p. 133) 2762 liters O₂ used and 2670 liters CO₂ produced which equals a respiratory quotient of 0.967. Gases due to fermentation equal 242 liters CH₄ and 681 liters CO₂ in 24 hours, thus the ratio of CH₄ to CO₂ being 1:2.81. In computing the energy production Mollgaard and Anderson make use of the respiratory quotient and claim very satisfactory results.

Applying to the pulmonary gas exchange the 681 liters fermentation CO_2 we get a respiratory quotient for the total gas exchange of 1.213.

In Klein's Regnault-Reiset experiments referred to, one point was not determined which introduced an uncertainty in the respiratory quotient, namely, the amount of fermentation CH_4 and CO_2 which is absorbed in the body and escapes through the lungs. Zuntz and Lehmann have found that there is a small loss of CH_4 through the lungs in the case of the horse where the fermentation mostly takes place in the colon and from Klein's experiments with the ox it seems as though considerable fermentation gases could have left the body through the lungs.

The respiration calorimeter in use at the Institute of Animal Nutrition, State College, Pa., is not a closed circuit apparatus, nor have any tracheal respiration experiments been attempted in connection with it. A few years ago, however, it was thought desirable to try to determine the amount of oxygen consumed besides the total amount of CO_2 and CH_4 produced by the animal while in the respiration calorimeter by the use of the principle of the Jaquet apparatus. By applying a factor for the fermentation CO_2 in relation to the CH_4 it would then be possible to compute the true pulmonary respiratory quotient. The value of such a factor is at present not fully determined.

We realized that in order to obtain reliable results on the oxygen it would be necessary to take and analyze large continuous samples of the ventilating air current. Not knowing of any existing suitable method for the purpose, or that one was at that very time being developed in Denmark, the writer devised and in the course of time succeeded in developing a new method which was tested out in the animal nutrition laboratory. Since no description of this method has been published a brief explanation of it is necessary.

The method consists in removing the oxygen from the outcoming air by means of heated charcoal, and absorbing and weighing the amount of gases formed. A 200-liter aspirator is used for sampling and the collection of the nitrogen of the air sample. The air for analysis is first freed from its H_2O and CO_2 by means of sulfuric acid pumice stone and soda lime, after which it passes through a large silica combustion tube which contains of tested charcoal a quantity large enough to take care of over 300 liters air. This tube which is in a vertical position is heated only over a short section by means of a small electric heating unit. The gases formed by combustion, after the water has been removed, are passed through an absorption set consisting of two KOH

bottles followed by two large soda lime tubes and an acid pumice tube. After being freed from all CO_2 and H_2O the gases pass through a second combustion tube filled with CuO heated to redness to oxidize any CO which is present, and then through another set of soda lime and acid pumice stone tubes in which the CO_2 formed from CO is weighed. The nitrogen passes on to the aspirator in which it is measured. In developing the method many difficulties were encountered because of the physical properties of the charcoal in regard to gases, but all were finally successfully overcome, and the method which although in its present form is rather complicated gave good results. The average of three closely agreeing blank tests of outdoor air was 20.927 per cent oxygen, CO_2 free basis = 20.920 per cent O_2 in air.

Thus, counting non-combustible rarer gases as nitrogen, the composition of the outdoor air will be as follows:

	OUTDOOR AIR	OUTDOOR AIR CH_4 FREE BASIS
	<i>per cent</i>	<i>per cent</i>
N_2	79.045	79.0465
O_2	20.920	20.9204
CO_2	0.033	0.0330
CH_4 and H_2	0.002	

Only two of the trial tests with animals were free from accidents and thus available for respiratory quotient determination. Without going into details of the method the main data for computation of the respiratory quotient are given below for these two experiments with milking cows during which the oxygen was determined by the charcoal method. Each set of data covers one subperiod of 12 hours between 6:00 p.m. and 6:00 a.m. The animals were fed twice a day with equal portions of the feed at 6:00 p.m. and 6:00 a.m. (Table 3, see page 62.)

Taking into account only the total oxygen used and the CO_2 produced in the chamber we have the following respiratory quotients:

	cow 885	cow 886
	<i>liters</i>	<i>liters</i>
O_2 ingoing.....	44.1558	45.5362
O_2 outcoming.....	43.7792	45.2522
O_2 used.....	0.3766	0.2840
CO_2 produced.....	0.5847	0.4594
Respiratory quotient.....	1.552	1.6180

TABLE 3

Data for computing respiratory quotients from two respiration experiments

TESTS AND FACTORS	12-HOUR PERIOD	cow 886 3/5-6/18 DAILY RATION: 3.40 kgm. hay 5.08 kgm. grain	cow 885 5/14-15/18 DAILY RATION: 2.11 kgm. hay 3.15 kgm. grain
		liters	liters
Respiration calorimeter experiment	Total (ventilation) outcoming air including N ₂ , O ₂ and CO ₂ at 0° and 760 mm.....	472,712.41	480,273.32
	Total CO ₂ produced....	1,309.519	1,013.66
	CH ₄ produced.....	119.88	92.01
Air analysis by the charcoal method	Sample of outcoming air for oxygen determination gave		
	Nitrogen.....	166.8410	172.0560
	Oxygen.....	43.7792	45.2522
	Carbon dioxide.....	0.5847	0.4594
		211.2049	217.7676
Using outdoor air composition, CH ₄ free basis	The volume of N ₂ found in air sample represents incoming air equal to.....	211.066	217.664
	Oxygen equivalent in incoming air.....	44.1558	45.5362

In this work any error appears magnified in the final results but, aside from analytical error, these results point to some other source for CO₂ than the usual catabolism of feed in the animal tissues.

Applying the facts brought out by Mollgaard and Anderson and by Klein, namely, that for every liter of CH₄ leaving the body directly from the intestinal tract there is also a certain amount of CO₂ given off which is due to an anaerobic fermentation process, the above values of the respiratory quotient will be reduced.

The ratio of CH₄ to CO₂ given by Mollgaard and Anderson was 1:2.81 which for 119.88 and 92.01 liters CH₄ would correspond to 336.863 and 258.548 liters CO₂ respectively. Subtracting these volumes of CO₂ from the total ventilation and from the total CO₂ produced, and recomputing the new CO₂ values back to the volume of the air sample we have the prespiratory quotients shown in table 4.

TABLE 4

Respiratory quotient computed using Mollgaard and Anderson's factor for fermentation gases

	cow 886		cow 885	
	Ventilation	CO ₂	Ventilation	CO ₂
	liters	liters	liters	liters
Total ventilation and CO ₂ ...	472,712.41	1,309.519	480,273.32	1,013.66
Total fermentation CO ₂	336.863	336.863	258.548	258.548
Corrected total ventilation and CO ₂	472,375.547	972.656	480,014.772	755.114
Air sample for O ₂ det.....	211.066	0.4346	217.664	0.3424
O ₂ used.....		0.3766		0.2840
Respiratory quotient.....		1.154		1.210

If instead of the ratio 1:2.81 for CH₄ to CO₂ the value found by Markoff for the gas taken directly from the paunch of an animal, which was 1:3.68, is used, or if we take it for granted that there is an absorption of CO₂ from the alimentary tract and loss of the same through the lungs, and use Markoff's ratio of 1:5.19 for CH₄ and CO₂ due to fermentation and repeat the computation we would have the following:

	RESPIRATORY QUOTIENT	
	Cow 886	Cow 885
CH ₄ to CO ₂ ratio = 1:3.68.....	1.031	1.078
CH ₄ to CO ₂ ratio = 1:5.19.....	0.816	0.856

From this present uncertainty about the respiratory quotient we may well conclude that it does not furnish a short cut to the accurate computation of the energy metabolism of the animal. On the contrary we must expect that as the nutrition problems become more and more complex, more accurate, more refined, more comprehensive methods will also be needed and that the research worker must call to his aid not only general chemistry and physics but bacteriology, biological chemistry, etc., to help solve his problems.

Thus one of the fundamental questions in reference to the respiratory quotient determination by the open circuit Pettenkofer or Jaquet and other methods as yet undetermined is that of the ratio of the CH₄ to CO₂ as produced throughout the whole intestinal tract of the animal.

In reference to the pulmonary respiration experiments the important point is to know how much of the fermentation CH_4 and CO_2 is absorbed into the blood and is escaping through the lungs so that proper corrections can be applied for them. Based upon work already done but which at present is by no means perfect some factors could perhaps be agreed upon tentatively and used until better ones are established.

Another question, perhaps not of so much importance yet demanding an answer, is whether the oxygen of the air taken into the digestive tract with the food is absorbed into the blood, or whether some aerobic process is going on simultaneously with the anaerobic, in the digestive tract, thus, in turn, to some small degree at least masking the fermentation process.

BIBLIOGRAPHY

- (1) BENEDICT: Carnegie Inst. of Washington, Pub. 77, 189.
- (2) CARPENTER: Carnegie Inst. of Washington, Pub. 216.
- (3) KLEIN: Biochem. Zeitschr., 1916, lxxii, 169.
- (4) MARKOFF: Biochem. Zeitschr., 1913, lvii, 1.
- (5) MOLLGAARD AND ANDERSON: 94^{de} Beretning fra Forsogslaboratoriet, Copenhagen.

SOME FUNDAMENTALS OF STABLE VENTILATION

By HENRY PRENTISS ARMSBY, *Director*, and MAX KRISS, *Associate*, Institute of Animal Nutrition of the Pennsylvania State College

COOPERATIVE INVESTIGATIONS BETWEEN THE BUREAU OF ANIMAL INDUSTRY OF THE UNITED STATES DEPARTMENT OF AGRICULTURE AND THE INSTITUTE OF ANIMAL NUTRITION OF THE PENNSYLVANIA STATE COLLEGE

Much study has been given in the past to the mechanical aspects of stable ventilation and to the construction of efficient systems; but, so far as the authors are aware, singularly little attention has been paid to the amount of motive power available for the operation of these systems. This is particularly true of that portion of it which is derived from the heat production of the animals, notwithstanding the fact that the latter may vary within wide limits and may at times constitute the sole motive power.

In the cooperative investigations upon animal nutrition which have been carried on at this institute during the past 20 years, a large number of direct determinations of the heat production of cattle under different conditions have been made. Numerous similar determinations have also been made by Kellner (11, 12, 13)¹ by the method of indirect calorimetry. A smaller number of results upon other species of farm animals are also on record. Upon the initiative and with the efficient cooperation of Mr. W. B. Clarkson, chairman of the Committee on Farm Building Ventilation of the American Society of Agricultural Engineers, we have attempted to work out a method by which these results may be applied to the problems of stable ventilation and the heat production in any specific case computed with a fair approximation to accuracy. The present paper contains the results of these endeavors.

INTRODUCTION

The installation of an effective ventilating system must necessarily depend, first, on a knowledge of the scientific principles involved and, second, upon a study of the conditions of each individual case. As the amounts of pure air required by the different species of farm animals are different, the minimum volume of air movement through a stable must vary accordingly. The construction of a ventilating system must be based on the unit of air movement chosen and on the available motive power which is to ensure the required supply of air.

¹ Reference is made by number (italic) to "Literature cited," p. 367-368

The motive power utilized in stable ventilation is chiefly the passing wind and the heat and water vapor given off by the animals. It frequently happens, however, that the motive force due to the wind is very small or even zero. At such times the air movement is entirely dependent upon the motive power derived from a rise in temperature and from an increase in the moisture content of the air after it enters the stable. It is therefore important to know this minimum motive power—that is, the heat and water vapor supplied by the animals, as this knowledge is evidently fundamental in determining the proper dimensions of the ventilating system.

But the heat given off by farm animals, while serving as a motive power for ventilation, is also relied upon to maintain the temperature of the stable at a comfortable degree in cold weather. The Committee on Farm Building Ventilation of the American Society of Agricultural Engineers in its recent report (8) to the society has emphasized very strongly the need of effective control of the temperature in farm buildings, as based on a number of its investigations. The committee found many barns with well-equipped ventilating systems which were not producing satisfactory results to the owners, not because of inadequate ventilation, but because of the fact that the buildings were too cold. All these facts point to the necessity of knowing how much heat is given off by the different farm animals and is available for heating and ventilating purposes.

Besides heat and water vapor farm animals give off carbon dioxide and some volatile organic products. Air once respired contains carbon dioxide in a quantity which makes it unfit to be breathed again unless very much diluted with pure air. It is chiefly the carbon-dioxide content of the air that serves as a basis for determining its degree of purity. In selecting a unit of air movement in the construction of a ventilating system it appears, therefore, that a knowledge of the average amounts of carbon dioxide produced by the different animals must be of not a little significance.

AMOUNT OF AIR REQUIRED FOR DIFFERENT SPECIES AND STANDARD OF PURITY

From what has just been said it is clear that the question of stable ventilation is a question of maintaining the proper purity of air in the stable as well as the proper temperature. Air supports the life of the animal. The air an animal breathes is as much an indispensable part of the feed it consumes as is the hay or the grain eaten. Within the animal body neither assimilation of food nor generation of energy can take place without the consumption of a proportionate amount of air. When the animals are outside they have plenty of pure air at their disposal; in the stable, however, the air is contaminated with the gases thrown off by them. Unless there is an air movement at a proper rate into and

out of the stable, these gases—the carbon dioxide and the volatile organic products exhaled by the animals—will accumulate and may have injurious effects on them.

King (14) bases his estimates of the volume of air which should move continuously through stables, first, on the amount of pure air which must be breathed by different animals and, second, on the standard of purity recommended by him. According to his computations a horse must draw into and force out of his lungs, on the average, each hour, some 142 cubic feet of air, the cow 117, the pig 46, and the sheep 30 cubic feet.

The standard recommended by King requires a degree of purity of air not lower than 96.7 per cent.—that is, that the air in the stable shall at no time contain more than 3.3 per cent of air once breathed. Since the air coming from the lungs contains about 4.24 volume per cent of carbon dioxide and pure air 0.028 volume per cent, it appears that King's standard allows $4.24 \times 0.033 + 0.028 \times 0.967$, or 0.167 volume per cent of carbon dioxide. From the amounts of air breathed by the different animals given above, the rate at which air must enter and leave the stable to correspond to this standard is computed per hour and per head as follows:

For horses:	$\frac{142 \times 100}{3.3} = 4,303$	cubic feet.
For cows:	$\frac{117 \times 100}{3.3} = 3,545$	cubic feet.
For swine:	$\frac{46 \times 100}{3.3} = 1,394$	cubic feet.
For sheep:	$\frac{30 \times 100}{3.3} = 909$	cubic feet.

It is not claimed that the standard of air purity and the units of air movement for the different animals given above are absolutely needed. While they probably afford a good gauge by which to be guided, they have been given here mainly to illustrate the method and the basis of their computation.

MOTIVE POWER FOR STABLE VENTILATION

The maintenance of a flow of air through a building requires the continuous expenditure of energy, and the amount of this energy and the work done will be in direct proportion to the weight of air moved through the ventilated space and the resistance it is necessary to overcome in accomplishing this movement. To supply air to 100 horses, for example, at the rate of 4,303 cubic feet per hour and per head, the necessary amount of work is that of moving through the stable each hour $\frac{4,303 \times 0.08 \times 100}{2,000}$

or 17.2 tons, 0.08 representing the weight of 1 cubic foot of air in pounds.

The power used to accomplish the air movement through stables, as already stated, is chiefly the passing wind and the heat and moisture given off by the animals. The motive force due to the wind depends on its velocity, direction, etc., and is, in general, very variable and sometimes

even zero. On the other hand, the amounts of heat and water vapor given off by animals are fairly constant under like conditions and must, therefore, be depended upon to cause a flow of air sufficient to supply the minimum amount needed. Since it is this minimum air movement that concerns us most, only the motive power derived from the heat and water vapor produced by the animals will be considered here.

ANIMAL HEAT AS A MOTIVE POWER IN VENTILATION

The immediate cause of air movement into and out of a ventilated space is a difference of pressure established between the air in the space to be ventilated and that outside. The effect of the heat given off by the animals is to render the air of the stable relatively lighter than the air outside. This difference in density causes a difference in pressure, which tends to maintain a continuous flow of air into and out of the stable.

The difference in pressure between the air in the barn and that outside resulting from a difference in temperature can be computed in the following way: When air is warmed its volume expands $1/491$ of its volume at 32° F. for each degree Fahrenheit rise in temperature. This expansion tends to force out 1 cubic foot of air for each 491 cubic feet contained in the stable, and the air remaining will consequently weigh less than an equal volume outside by an amount equal to the weight of the air thus forced out. If, for example, in a stable containing 19,640 cubic feet, or one very nearly 40 by 40 by 12.3 feet, the temperature is raised to 57° , as compared with 32° outside, the air forced out by expansion will be $\frac{19,640 \times 25}{491}$, or 1,000 cubic feet. In other words, the air remaining will weigh 80 pounds less than an equal volume outside. This means that the total pressure into the stable at the floor is 80 pounds greater than that exerted outward by the inside air; and, since the floor has an area of $40 \times 40 = 1,600$ square feet, the pressure tending to force air into the stable at a floor opening and out at the ceiling is $\frac{80}{1,600}$, or 0.05 pound per square foot.

Based on the foregoing considerations, the magnitude of the temperature effect in producing draft, according to King, is represented by the following equation:

$$\text{Cubic feet per hour} = 60 \times 60 \times 8 \sqrt{\frac{T-t}{491}} H,$$

in which—

60×60 is the number of seconds per hour,

8 is $\sqrt{2g}$, g being the value of gravity, 32.16 feet per second,

T is the temperature of air inside,

t is the temperature of air outside,

H is the height of room or ventilator,

$1/491$ is the expansion of air for 1° F.

This equation gives the theoretical value of the air flow per square foot of cross section. The actual flow of air is, however, less than the theoretical, its relative value depending on the resistance which the moving air has to overcome. It appears from an examination of the equation that in order to determine the flow of air the height and the cross section of the ventilator and the difference in temperature between the inside and outside air must be known. On the other hand, from the unit of air movement chosen and the difference in temperature likely to exist the minimum size of the ventilator can be determined.

What difference in temperature can be maintained by the heat given off by the different animals when the ventilation is sufficient to supply the minimum amount of air needed is a question which will be considered later in its relation to heat emission.

WATER VAPOR AS A MOTIVE POWER IN VENTILATION

The water vapor which the animals give off is under ordinary conditions taken up by the moving air and carried off as rapidly as it is formed. The addition of the water vapor to the air in the stable tends to make it lighter than that outside, and this effect serves as a measure of the influence of water vapor as a motive power in ventilation.

The higher the temperature of the air the greater is its moisture-holding capacity. The more moisture the air contains the lighter it is. Consequently, the motive power derived from the water vapor is greater the higher the temperature of the stable air and the more completely it is saturated.

The quantities of water vapor produced by the different animals are given later. The motive power derived from the moisture is much less than that derived from the heat; and, since its magnitude largely depends on the difference in temperature, it can be considered only as secondary in importance.

PRINCIPLES INVOLVED IN THE PRODUCTION OF HEAT BY ANIMALS

The function of the animal heat as a motive power for stable ventilation has already been considered. A second function of the animal heat is to keep the stable warm in cold weather. The optimum temperature to be maintained in the stable varies with the kind of animal and also with the ration. There exists also a certain relation between the heat given off by the animal and its thermal surroundings. For the purpose of estimating approximately the best stable temperature, both as regards comfort and economy, it appears desirable to turn to a consideration of the scientific principles involved.

REGULATION OF BODY TEMPERATURE

Farm animals belong to that general class known as warm-blooded animals, whose bodies during health maintain a nearly constant temperature which is the resultant of two factors, thermogenesis, or the

development of heat inside the body, and thermolysis, the loss of heat from the body, principally by radiation and conduction and as latent heat of water vapor. The external temperature tends to influence the outflow of heat, but the animal is able to regulate it by physical and chemical methods.

There is a certain external temperature, called the critical temperature, at which the outflow of heat just balances the necessary heat production of the animal as a result of internal work. Above this temperature the radiating capacity of the body surface is varied to meet the varying conditions; below it, this method of regulation is largely exhausted, and therefore more or less oxidation of tissue is required to maintain the normal temperature of the body.

EFFECT OF FEED CONSUMPTION ON THE HEAT PRODUCTION AND ON THE CRITICAL TEMPERATURE

It is a fact demonstrated by numerous experiments that the consumption of feed results in increasing the heat production of an animal. When an animal is fasting it produces a certain amount of heat due to the vital functions of the internal organs. This is generally termed basal, or fasting katabolism. When the animal is fed, its heat production is increased over that of the fasting state. This increment of heat brought about by the consumption of feed has been ascribed to various causes, one of which is the expenditure of energy in the digestion and assimilation of the feed, often collectively termed "work of digestion."

The more heat the animal produces the more cold it naturally can withstand without being compelled to oxidize body tissue in order to maintain the normal body temperature. This, in other words, means that the consumption of feed lowers the critical temperature, the effect varying with the nature and quantity of the feed. Animals fed heavily, as in productive feeding, can therefore withstand more cold, or have a lower critical temperature, than animals kept on a simple maintenance ration, while the critical temperature of the latter is higher than that of the fasting animal.

EFFECT OF LOW THERMAL SURROUNDINGS ON MAINTENANCE REQUIREMENT

From what has just been said it appears that a ration sufficient for maintenance at a temperature higher than the critical may be insufficient for maintenance when the thermal surroundings are lower than the critical, because of the failure to meet the demand for heat. What the critical temperatures of the different farm animals are is therefore a question not only of physiological but also of economic significance.

It is apparent, however, that the critical temperatures of farm animals do not lend themselves to accurate determination. At best they are estimated only approximately. A summary of the results of different

investigators on this subject (3, p. 312) shows that the critical external temperature for the horse is high as compared with that of ruminants, so that a ration which is sufficient for maintenance in summer may be insufficient in winter. The critical temperature for swine has been likewise found to be comparatively high (68° to 73° F.), which means that exposure to low temperatures may be expected to increase the actual maintenance ration and the heat production of swine, and this has been confirmed by experimental results. On the other hand, the results on cattle seem to indicate that their critical temperature is rather low (much below 56°), which means that cattle can be exposed to lower temperatures than horses or swine before their maintenance requirement will be affected and their heat production stimulated.

EFFECT OF LOW THERMAL SURROUNDINGS ON PRODUCTIVE FEEDING

The production of meat or milk implies the consumption of large quantities of feed. Since the latter is the source of a large amount of heat, due to the "work of digestion," which has to be removed at a correspondingly rapid rate, it appears that heavy producers are better adapted to relatively cold thermal surroundings. Furthermore, since it is the aim in feeding such animals to induce them to eat as much feed as can be economically converted into useful products, it seems desirable, on the one hand, that the thermal surroundings should be low in order to maintain the appetite of the animals and, on the other, not so low as would cause wasteful oxidation for simple heat production.

The question whether winter feeding for fattening can be accomplished to better advantage in the stable than in the open shed has interested many investigators, and a considerable amount of experimental work is on record. The results (1) show in general that cattle are best adapted to exposure—that is, they produce as good results when exposed as when stable fed. Swine are least adapted to exposure, the gain of the animals exposed to severe weather being frequently negative, while sheep seem to take an intermediate place. These results are in full harmony with the findings given above as regards the critical temperature. Less decisive results have been obtained with dairy cows, but it appears fairly well established that for well-fed animals the need for warm stables has been somewhat overemphasized.

OPTIMUM STABLE TEMPERATURE

Both theoretical considerations and the results of experience show that a certain excess of heat production over that absolutely required to maintain the body temperature is likely to be advantageous, both by promoting the comfort of the animal and as providing a margin of safety. On the other hand, an unnecessarily high temperature tends to affect the appetite and general health of the animal. From this it follows that the best thermal surroundings for animals lie between these limits—

namely, somewhat above the critical point, but not so much as to affect the appetite and thrift. These limits, evidently, will vary with the species of animal and with the amount and character of the ration. The best temperature surroundings for animals being fed high, according to King, are likely to lie between 45° and 50° F., while for animals on a maintenance ration, the best temperatures may be between 55° and 65°. For dairy cows having large udders only scantily clothed with hair and through which much blood must flow, a temperature as high as 50° to 60° is considered as probably the best.

Whether the heat eliminated by animals is sufficient to maintain in the stable approximately these temperatures in cold weather when the air movement is at the proper rate will be considered on subsequent pages.

METHOD OF COMPUTING HEAT PRODUCTION

The discussions of the foregoing paragraphs make it evident that the heat produced by an animal may be regarded as the sum of two factors, first the necessary internal work due to the vital activities of the internal organs and, second, the "work of digestion." The first gives rise to an amount of heat equivalent to the fasting katabolism, which varies with the species and size of the animal, while the second gives rise to an increment of heat due to feed consumption, which varies with the character and quantity of the ration. It is clear, then, that no single standard value can be assumed as representing even approximately the heat production of any species.

When the fasting katabolism of an animal and the heat increment due to the feed eaten are known, it is evident that the total heat produced by the animal can be computed by simple addition. Experimental data are available from which it is possible to estimate more or less accurately the fasting katabolism of farm animals according to their live weights, and also the increment of heat due to the ration feed. These data have been used as the general basis for computing the heat production. The details of the method are best illustrated by the computation on subsequent pages of the heat production of dairy cows.

ACCURACY OF THE COMPUTATIONS

The reader should beware of being led by the apparently very exact figures of the tables on succeeding pages to ascribe to these data a greater degree of accuracy than they really possess.

In the first place they represent specific cases assumed to be more or less typical. The actual production of heat, carbon dioxide, and water by a given species will show wide variations from stable to stable, and in the same stable from time to time, according to the size of the animals, their degree of activity, and especially the amounts of feed which they consume.

In the second place, it is by no means intended to assert on page 354, for example, that every Jersey cow weighing 750 pounds and yielding 20 pounds of 5 per cent milk will produce exactly 16,313 calories of total heat. The computations have been made on the basis of average results from which those on an individual animal may vary considerably. This is especially true of the fasting katabolism. Moreover, the computations have been carried out to the nearest whole calorie so as to record the exact results of the calculation. In view, however, of the many possibilities of experimental error involved, it seems very questionable whether the last three digits are significant. Probably an estimate to the nearest thousand calories—that is, to one therm—would be all that is justified and would be sufficiently accurate for the discussion of all ventilation problems.

HEAT PRODUCTION OF CATTLE

FASTING KATABOLISM

The data for the fasting katabolism of cattle, although obtained by indirect methods and not by actually starving the animals, are more trustworthy than those for any other species of farm animals for the reason that they are more abundant, are concordant, and are based largely on experiments with the respiration calorimeter by means of which direct determinations of the heat production were made. In these experiments the animal is usually fed two different amounts of the same feed, and the effect of this on the heat production—that is, the decrease of heat production per pound decrease of feed—is determined. From this it is estimated how much heat would be produced if all the feed were withdrawn—that is, if the animal were reduced to the fasting state.

The average given by Armsby (3, p. 711) for the fasting katabolism of cattle per 1,000 pounds live weight is 6 therms, or 6,000 calories, and, as the fasting katabolism of animals of the same species has been found to be approximately proportional to the two-thirds power of their live weight, that of cattle is computed accordingly. Table I gives the fasting katabolism of cattle according to their live weight in terms of calories.

TABLE I.—Fasting katabolism of cattle

Live weight.	Calories, per head.	Live weight.	Calories, per head.
150	1,690	1,000	6,000
250	2,380	1,250	6,960
500	3,780	1,500	7,860
750	4,950		

HEAT INCREMENT DUE TO THE CONSUMPTION OF FEED BY CATTLE

The energy expended by cattle in the increased body activities connected with the digestion and assimilation of many feeding stuffs have been determined directly by varying the amount of the feeding stuff in

the ration and by determining the heat production. From a comparison of two determinations the heat increment caused by a pound of feeding stuff can be determined. The data for the heat increment caused by different feeding stuffs are average figures computed by Armsby and Fries (4, 5) from the results of their own experiments and those of Kellner and Köhler (11, 12, 13) on beef cattle and are given in Table II in calories per pound of dry matter. The corresponding figures for dairy cows would probably be somewhat less, but how much less has not yet been determined.

TABLE II.—Increment of heat production by cattle per pound of dry matter consumed

Feeding stuffs.	Experimenters.	Energy expenditure.
		Calories.
Roughage:		
Timothy hay.....	Armsby and Fries.....	354.7
Red clover hay.....	do.....	441.3
Do.....	Kellner and Köhler.....	422.7
Mixed hay.....	Armsby and Fries.....	444.5
Alfalfa hay.....	do.....	530.3
"Grass hay".....	Kellner and Köhler.....	474.0
Meadow hay.....	do.....	568.8
Rowen.....	do.....	434.6
Corn stover.....	Armsby and Fries.....	483.1
Barley straw.....	Kellner and Köhler.....	397.8
Oat straw.....	do.....	460.0
Wheat straw.....	do.....	516.2
Straw pulp.....	do.....	526.2
Concentrates:		
Corn meal.....	Armsby and Fries.....	583.3
Hominy chop.....	do.....	619.2
Wheat bran.....	do.....	533.9
Cottonseed meal.....	Kellner and Köhler.....	443.6
Linseed meal.....	do.....	547.9
Palmnut meal.....	do.....	456.8
Peanut meal.....	do.....	525.7
Beet molasses.....	do.....	448.2
Starch.....	do.....	566.1
Peanut oil.....	do.....	783.4
Wheat gluten.....	do.....	950.8

In its relations to stable ventilation the computation of the heat production of cattle is of special interest in the case of dairy cows, since in cold climates these animals are almost always stabled during the winter while beef cattle are quite commonly fed in the open. The computations for cows are therefore given in considerable detail in the following paragraphs.

TYPICAL WEIGHTS AND RATIONS OF DAIRY COWS

Obviously, no single value can be given for the heat production of the dairy cow, since it varies widely according to the size of the animal and the amount of feed consumed. All that is possible is to select certain typical live weights and rations and to compute the corresponding heat production as illustrations of the method in its application to specific

cases, such as may be found in good practice. The typical weights and rations upon which the computation of the heat emission by dairy cows has been based are those suggested, at the request of Mr. Clarkson, by Prof. C. H. Eckles, of the University of Minnesota.

TABLE III.—Typical live weights and rations

Breed.	Live weight.	Daily milk yield.		Daily ration.			
		Pounds.	Percentage of fat.	Corn silage.	Alfalfa hay.	Grain mixture. ^a	Additional linseed meal.
	Pounds.			Pounds.	Pounds.	Pounds.	Pounds.
Jersey.....	900	20	5.0	30	8	6	.....
Do.....	900	30	5.0	30	8	9	I
Holstein.....	1,250	30	3.5	40	10	6	.....
Do.....	1,250	45	3.5	40	10	10	I

^a Composed of ground corn 4 parts, wheat bran 2 parts, linseed meal 1 part.

COMPUTATION OF THE HEAT PRODUCTION OF DAIRY COWS

To compute, for example, the daily heat production by the typical Jersey cow giving 20 pounds of milk daily, it is only necessary to add to the fasting katabolism of a cow weighing 900 pounds the heat increment due to the ration consumed. According to Table I the fasting katabolism of a cow weighing 1,000 pounds is 6,000 calories, while that for one weighing 750 pounds is 4,950 calories. From these figures the fasting katabolism of a cow weighing 900 pounds may be estimated with sufficient accuracy by simple proportion as being 5,580 calories per day.

It remains to figure out the heat increment caused by the consumption of feed. By using the average percentages of dry matter in the feeds as given in Henry and Morrison's tables (10) it is found that the amounts of dry matter contained in the ration are:

In corn silage.....	7.9 pounds.
In alfalfa hay.....	7.3 pounds.
In grain mixture.....	5.4 pounds.

Since the grain mixture consists of 4 parts of corn, 2 parts of wheat bran, and 1 part of linseed meal, the heat increment per pound of dry matter of the grain mixture (Table II) is:

$$1/7(583.3 \times 4 + 533.9 \times 2 + 547.9 \times 1) = 564.1 \text{ calories.}$$

The heat increment per pound of dry matter of alfalfa hay is 530.3 calories, and that of corn silage is assumed to be 483.1 calories—that is, the figure corresponding to corn stover—since no figure for corn silage is available. From these figures the total heat increment caused by the ration is obtained as follows:

Corn silage.....	483.1 × 7.9 = 3,816 calories.
Alfalfa hay.....	530.3 × 7.3 = 3,871 calories.
Grain mixture.....	564.1 × 5.4 = 3,046 calories.
Total heat increment.....	10,733 calories.

Adding to this the fasting katabolism of the Jersey cow, 5,580 calories, gives the total heat production per day as 16,313 calories.

Computed by this method, the total heat production by the cows per day per head is shown in Table IV.

TABLE IV.—Total heat production by typical cows per day per head

Animal.	Calories.
Jersey cow producing 20 pounds of milk.	16,313
Jersey cow producing 30 pounds of milk.	18,273
Holstein cow producing 30 pounds of milk.	19,905
Holstein cow producing 45 pounds of milk.	22,372

HEAT GIVEN OFF BY RADIATION AND CONDUCTION AND AS LATENT HEAT OF WATER VAPOR

The heat emission as computed above includes that given off by radiation and conduction and the latent heat of the water vaporized. The latent heat of water vapor, however, can hardly be regarded as available for ventilation purposes, inasmuch as under average conditions there is no considerable accumulation of condensed water, the water vapor being removed from the barn as rapidly as it is produced by the animals so that there is little chance for its latent heat to be liberated.

From the experiments on cattle with the respiration calorimeter it has been found that except on very heavy rations the latent heat of water vapor constitutes approximately 25 per cent of the total heat given off, while about 75 per cent is eliminated by radiation and conduction. On this basis, the heat emission by radiation and conduction and as latent heat of water vapor per day per head for cows has been computed (Table V).

TABLE V.—Heat given off by radiation and conduction and as latent heat of water vapor per day per head by typical cows

Animal.	Heat emission by radiation and conduction.	Latent heat of water vapor.
	Calories.	Calories.
Jersey cow producing 20 pounds of milk.	12,235	4,078
Jersey cow producing 30 pounds of milk.	13,705	4,568
Holstein cow producing 30 pounds of milk.	14,929	4,976
Holstein cow producing 45 pounds of milk.	16,779	5,593

WATER VAPOR PRODUCED BY COWS

The computation of the amount of water vapor produced by an animal when the latent heat of the water vapor is known is a very simple matter. The latent heat of 1 gm. of water vapor is 0.587 calorie. By

dividing, therefore, the calories of latent heat of water vapor by 0.587 the number of grams of water vapor produced is obtained. In the foregoing cases the computed amounts per day and per head are as shown in Table VI.

TABLE VI.—Water vapor produced by typical cows per day and per head

Animal.	Water vapor.
	Gm.
Jersey cow producing 20 pounds of milk.	6,947
Jersey cow producing 30 pounds of milk.	7,782
Holstein cow producing 30 pounds of milk.	8,477
Holstein cow producing 45 pounds of milk.	9,528

CARBON DIOXID PRODUCED BY COWS

Since carbon dioxide is a product of combustion, however slow it may be, within the animal body, it is natural to expect that a more or less definite relation between the heat production and the output of carbon dioxide must exist. From the accumulated data of the heat emission and carbon dioxide production by cattle determined directly by means of the respiration calorimeter at this Institute, the relation of the carbon dioxide produced to the heat given off has been very recently established by Armsby, Fries, and Braman (6), who, on comparing the daily output of carbon dioxide and the heat production by steers and cows for 188 separate days, found that in each case the ratio of the carbon dioxide produced in grams to the total heat emission in calories was very close to 1 to 2.5, or 0.4, the mean ratio being 1 to 2.495. By making use of this factor the amount of carbon dioxide produced by cows in grams is computed by simply multiplying the calories of daily heat emission by 0.4.

TABLE VII.—Carbon dioxide produced by cows per day and per head

Animal.	Carbon dioxide.
	Gm.
Jersey cow producing 20 pounds of milk.	6,525
Jersey cow producing 30 pounds of milk.	7,309
Holstein cow producing 30 pounds of milk.	7,962
Holstein cow producing 45 pounds of milk.	8,949

HEAT PRODUCTION OF COWS ON MAINTENANCE

The daily maintenance ration of cattle has been computed by Armsby (2) from a number of experiments in terms of metabolizable energy, which in this case also represents the total heat production, 10,500 calories being the average per 1,000 pounds live weight. This, com-

puted in proportion to the two-thirds power of the live weight, gives 9,788 and 12,184 calories, respectively, as the daily total heat production on maintenance by the Jersey and Holstein cows of the assumed weights. The heat emission by radiation and conduction, the water vapor, and the carbon dioxide produced by cows on maintenance have been computed by the methods just described and are included in the summary of the results of the computations on dairy cows in Table VIII.

TABLE VIII.—Heat, water vapor, and carbon dioxide produced by typical cows per day and per head

Animal.	Total heat emission.	Heat emission by radiation and conduction.	Latent heat of water vapor.	Water vapor.	Carbon dioxide.
	Calories.	Calories.	Calories.	Gm.	Gm.
Jersey cow producing 20 pounds of milk.....	16,313	12,235	4,078	6,947	6,525
Jersey cow producing 30 pounds of milk.....	18,273	13,705	4,568	7,782	7,309
Holstein cow producing 30 pounds of milk.....	19,905	14,929	4,976	8,477	7,962
Holstein cow producing 45 pounds of milk.....	22,372	16,779	5,593	9,528	8,949
Jersey cow on maintenance.....	9,788	7,341	2,447	4,169	3,915
Holstein cow on maintenance.....	12,184	9,138	3,046	5,189	4,874

HEAT PRODUCTION OF HORSES

HEAT INCREMENT DUE TO THE CONSUMPTION OF FEED

While the general principles of the computation of the fasting katabolism of horses are essentially the same as for cattle, the computation of the heat increment due to the consumption of feed is a much more complicated process. The reason for this lies in the fact that no calorimetric experiments for the direct determination of the heat production and of the balance of energy have been made with horses, and consequently an indirect method of computation of the heat increment has to be resorted to, which involves many estimates and calculations.

From the results of their experiments, Zuntz and Hagemann (18) estimate that the metabolizable energy of the feed of a horse equals 1,796 calories per pound of digestible nutrients; and they assume, on the basis of Magnus Levy's experiments on man, that 9 per cent of the metabolizable energy of the digestible nutrients consumed by a horse is converted into heat in the process of digestion. They furthermore compute from the results of their own experiments that each pound of total crude fiber consumed increases the heat production by 1,202 calories additional, so that the total heat increment due to consumption of feed by the horse is the sum of these two amounts. It is obvious that this method of computation necessitates a knowledge of the digestibility and of the total crude fiber content of the feed.

To illustrate the method of computing the heat increment due to the consumption of feed, that caused by a pound of oats is calculated as follows, the digestible nutrients being those given in Bulletin 186 of the Kansas Experiment Station (15), with the exception of those for clover hay, which are taken from Henry and Morrison's tables (10), from which have also been obtained the data for total crude fiber.

Digestible nutrients of oats

Protein.....	0.107 pound.
Carbohydrates.....	0.503 pound.
Fat (3.8×2.4).....	0.092 pound.

Total..... 0.702 pound.

Total crude fiber..... 0.109 pound.
Metabolizable energy..... 1,796 calories×0.702=1,260.8 calories.

Heat increment

9 per cent metabolizable energy..... 1,260.8×0.09=113.5 calories.
Additional for crude fiber..... 1,202 ×0.109=131.0 calories.

Total heat increment..... 244.5 calories.

The heat increment caused by other feeding stuffs has been computed in a similar manner.

FASTING KATABOLISM

The total heat production of the horse was estimated by Zuntz and Hagemann (18) from the respiratory exchange determined by means of a respiration apparatus for short periods after the consumption of different rations. From a comparison of the results and by the indirect method of computing the heat increment due to the work of digestion which has been illustrated they have computed the average fasting katabolism of the horse to be 4,100 calories per 1,000 pounds live weight. In proportion to the two-thirds power of the live weight the fasting katabolism of horses, as computed by Armsby, is given in Table IX.

TABLE IX.—Fasting katabolism of horses

Live weight.	Fasting katabolism per head.	Live weight.	Fasting katabolism per head.
	Calories.		Calories.
150	1,160	1,000	4,100
250	1,630	1,250	4,760
500	2,580	1,500	5,370
750	3,390		

TYPICAL WEIGHTS AND RATIONS OF HORSES

As examples of typical live weights and rations for horses upon which to base the computation of the heat production of these animals the following, suggested, at the request of Mr. Clarkson, by J. L. Edmonds, of the Illinois College of Agriculture, have been used.

Daily ration for light horses that get only about enough exercise to keep them in good condition per 1,000-pound horse:

- 8 pounds of oats.
- 2 pounds of wheat bran.
- 10 pounds of timothy hay.

Daily ration for 1,500-pound geldings at moderate work:

- 9 pounds of oats.
- 9 pounds of ear corn.
- 7½ pounds of timothy hay.
- 7½ pounds of clover hay.

TOTAL HEAT PRODUCTION

The total heat increment due to the ration fed, computed in the manner described, plus the fasting katabolism of the horse, gives the total heat production of horses of the weights and consuming the rations just specified when performing no work. The heat production is, of course, greatly increased during work, but plainly this additional heat is not ordinarily available as motive power for ventilation.

TABLE X.—Total heat production per day and per head by typical horses at rest

Animal.	Live weight.	Heat.
	Pounds.	Calories.
Light horses.....	1,000	10,853
Heavy work horses.....	1,500	14,835

HEAT EMISSION BY RADIATION AND CONDUCTION, WATER VAPOR, AND CARBON DIOXID PRODUCED BY HORSES

On the assumption that approximately the same relation exists as in the case of cattle between the total heat emission and the latent heat of water vapor and between the heat and the carbon dioxide produced by horses, a computation was made of the heat given off by radiation and conduction, the latent heat of the water vapor, the amount of water vapor, and the amount of carbon dioxide produced by horses. The method described above for cows was used, and the results are shown in Table XI.

TABLE XI.—Heat emission by radiation and conduction, water vapor, and carbon dioxide produced per day and per head by typical horses at rest

Animal.	Live weight.	Heat emission by radiation and conduction.	Latent heat of water vapor.	Amount of water vapor.	Carbon dioxide.
	Pounds.	Calories.	Calories.	Gm.	Gm.
Light horses.....	1,000	8,140	2,713	4,622	4,341
Heavy work horses.....	1,500	11,126	3,709	6,319	5,934

HEAT PRODUCTION OF SWINE

FASTING KATABOLISM

The fasting katabolism of swine has been determined independently by Meissl (16) and by Tangl (17) by starving the experimental animals for comparatively short periods and measuring the katabolism by means of a respiration apparatus. The average of their results, computed per 100 pounds in proportion to the two-thirds power of the live weight, is 1,250 calories. The fasting katabolism of swine, computed according to their live weight, is given in Table XII.

TABLE XII.—Fasting katabolism of swine

Live weight.	Fasting katabolism per head.	Live weight.	Fasting katabolism per head.
Pounds.	Calories.	Pounds.	Calories.
25	496	300	2,599
50	786	400	3,149
100	1,250	450	3,406
150	1,637	600	4,126
200	1,984		

HEAT INCREMENT DUE TO CONSUMPTION OF FEED BY SWINE

The data regarding the increment of heat production consequent on the consumption of feed by swine are rather meager. Of these, the results of several investigators on grains and on a mixed ration consisting of rice, flesh meal, and whey, as reported by Armsby (3, p. 656), are considered trustworthy; and the average of these, 417 calories per pound of dry matter eaten, is taken to represent the energy expenditure by swine.

RATIONS FOR SWINE

The rations and live weights of the animals, upon which the computation of heat emission by swine has been based, are those furnished at the request of Mr. Clarkson, by Prof. J. M. Evvard of Iowa Experiment Station. The weights of the animals and the daily feed eaten, reduced for convenience to dry matter, are the following:

Class.	Weight.	Dry matter of daily feed eaten.
		Pounds.
Suckling pig.....	25	1.29
Weanling pig.....	50	2.15
Shote, young.....	100	3.44
Shote, well-grown.....	150	6.02
Fattening hog.....	200	7.74
Farrowing hog.....	300	6.88
Breeding gilt.....	300	3.44
Breeding yearling sow.....	400	4.30
Breeding old sows, year or over.....	500	5.16
Breeding boar, young.....	300	3.44
Breeding boar, yearling.....	450	5.16
Breeding boar, old.....	600	6.02

TOTAL HEAT PRODUCTION OF SWINE

Since 417 calories represent the increment in heat production by swine per pound of dry matter eaten, the heat increment caused by the consumption of feed by swine is computed on the basis of the foregoing estimates by simple multiplication. To this the fasting katabolism of the animal as found in Table XII is added, and the total heat production is thus obtained (Table XIII).

TABLE XIII.—Total heat production of typical swine

Animal,	Live weight.	Total heat emission.
	Pounds.	Calories.
Suckling pig.....	25	1,034
Weanling pig.....	50	1,684
Shote, young.....	100	2,684
Shote, well-grown.....	150	4,147
Fattening hog.....	200	5,211
Farrowing hog.....	300	5,468
Breeding gilt.....	300	4,033
Breeding yearling sow.....	400	4,942
Breeding old sow.....	500	5,806
Breeding boar, young.....	300	4,033
Breeding boar, yearling.....	450	5,658
Breeding boar, old.....	600	6,636

HEAT EMISSION BY RADIATION AND CONDUCTION, WATER VAPOR, AND CARBON DIOXID PRODUCED BY SWINE

TABLE XIV.—Heat emission by radiation and conduction, water vapor, and carbon dioxid produced by typical swine per day and per head

Animal.	Live weight.	Heat emission by radiation and conduction.	Latent heat of water vapor.	Amount of water vapor.	Carbon dioxid.
	Pounds.	Calories.	Calories.	Gm.	Gm.
Suckling pig.....	25	776	259	441	414
Weanling pig.....	50	1,263	421	717	674
Shote, young.....	100	2,013	671	1,143	1,074
Shote, well-grown.....	150	3,110	1,037	1,767	1,659
Fattening hog.....	200	3,908	1,303	2,220	2,084
Farrowing hog.....	300	4,104	1,367	2,329	2,187
Breeding gilt.....	300	3,025	1,008	1,717	1,613
Breeding yearling sow.....	400	3,707	1,235	2,104	1,977
Breeding old sow.....	500	4,355	1,451	2,472	2,322
Breeding boar, young.....	300	3,025	1,008	1,717	1,613
Breeding boar, yearling.....	450	4,169	1,389	2,366	2,223
Breeding boar, old.....	600	4,977	1,659	2,826	2,654

The results of experiments on man (7) indicate that the heat emission by radiation and conduction is on the average not far from 75 per cent of the total heat emission, and that the relation of the carbon dioxid produc-

tion to the total heat production is likewise about the same as in cattle. The apparent agreement of these relationships between two so widely different species leads to the assumption that the results are, at least for this purpose, applicable also to swine. By using, therefore, the method of computation previously described for cattle, the heat emission by radiation and conduction, the latent heat of water vapor, the amount of water vapor, and the amount of carbon dioxid produced by swine are obtained.

HEAT PRODUCTION OF SHEEP

FASTING KATABOLISM

No direct determinations of the fasting katabolism of sheep are on record. From the rather scanty data regarding the maintenance ration of sheep available Armsby (3, p. 711) has computed by an indirect method, based on results with cattle, the fasting katabolism of sheep weighing 100 pounds to be 791 calories, and in proportion to the two-thirds power of live weight as given in Table XV.

TABLE XV.—Fasting katabolism of sheep

Live weight.	Fasting katabolism per head.	Live weight.	Fasting katabolism per head.
Pounds.	Calories.	Pounds.	Calories.
20	270	120	890
40	430	140	990
60	560	160	1,090
80	680	180	1,170
100	791	200	1,250

HEAT INCREMENT DUE TO CONSUMPTION OF FEED

No determinations of the increment of heat due to the consumption of feed by sheep have been reported, but it appears probable that the results obtained with cattle (Table II) may be applied to sheep without very serious error.

RATIONS FOR SHEEP

The average rations and live weights upon which the computation of the heat emission by sheep is based were taken from several sources. For fattening lambs, the average ration and live weight given by Henry and Morrison (10, p. 521) in their summary of the results on sheep of several different experiment stations were used as an example. For breeding ewes, the average ration and live weight given by Hackedorn (9) was used. The average ration for maintenance was taken from Bulletin 143 of the Bureau of Animal Industry, United States Department of Agriculture (2), the ration being given in terms of metabolizable

energy, which in a maintenance ration also represents the heat production. The respective live weights and rations per head in the two other cases are as follows:

Fattening lambs, average live weight 81.4 pounds—

Shelled corn, 1.3 pounds.

Alfalfa hay, 1.4 pounds.

Breeding ewes, average live weight 90.3 pounds—

Shelled corn, 0.27 pounds.

Wheat bran, 0.14 pounds.

Linseed meal, 0.05 pounds.

Clover hay, 2.08 pounds.

Silage, 2.09 pounds.

TOTAL HEAT PRODUCTION OF SHEEP

By applying to the foregoing rations the estimates and assumptions of the two preceding paragraphs, the total heat emission for sheep may be computed, and from that the heat emission by radiation and conduction, the latent heat of water vapor, the amount of water vapor, and the amount of carbon dioxide produced, exactly as for the other species. The results are as shown in Table XVI.

TABLE XVI.—Heat emission, water vapor, and carbon dioxide produced by typical sheep per day and per head

Animal.	Average live weight.	Total heat emission.	Heat emission by radiation and conduction.	Latent heat of water vapor.	Water vapor.	Carbon dioxide.
	<i>Pounds.</i>	<i>Calories.</i>	<i>Calories.</i>	<i>Calories.</i>	<i>Gm.</i>	<i>Gm.</i>
Fattening lambs	81.4	2,044	1,533	511	871	818
Breeding ewes	90.3	2,021	1,516	505	860	808
Sheep on maintenance . .	100.0	1,483	1,112	371	632	593

VENTILATION AND STABLE TEMPERATURE

The method employed by King to compute the rate of air flow for the different species has been given in an earlier paragraph of this paper. It was also shown that, assuming average figures for the percentage of carbon dioxide in the air coming from the lungs and in pure air, respectively, the air flow thus computed corresponds to 0.167 volume per cent of carbon dioxide in the stable air. Taking 0.167 per cent carbon dioxide as a standard, we have computed Table XVII, showing the rate of air flow that will be required to maintain this standard of purity when based on the average computed carbon-dioxide production by the different species in the examples shown in Tables VII, XI, XIV, and XVI. The last column in the table, giving King's figures for the air flow, has been inserted for the sake of comparison.

TABLE XVII.—Air flow per head to maintain 0.167 per cent carbon dioxide

Species.	Carbon dioxide produced per day.		Air flow per day.	Air flow per hour.	Air flow per hour according to King.
	<i>Gm.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>	<i>Cu. ft.</i>
Cows	^a 7,686	138.348	82,843	3,452	3,545
Horses	5,138	92.484	55,379	2,307	4,303
Swine	1,708	30.744	18,410	767	1,394
Sheep	740	13.320	7,976	332	909

^a Average carbon-dioxide production by cows in milk.

A glance at the last two columns of Table XVII reveals that while King's air flow for cows agrees fairly well with that computed from the carbon dioxide produced, those for other species differ very widely. In other words, either King's figures for volume of respiration in other species than cattle are too high or his assumption of a uniform percentage of carbon dioxide in the expired air is erroneous. At any rate, the actual carbon-dioxide production would seem to be the proper basis upon which to estimate the rate of ventilation required.

TEMPERATURE DIFFERENCE BETWEEN THE STABLE AND OUTSIDE AIR

As already shown, a considerable part of the motive power for stable ventilation is derived from the heat eliminated by the animals, and this heat is also depended upon to maintain the proper temperature in the stable. Obviously, the difference in temperature that can be maintained between the stable air and that outside depends, other things being equal, upon the balance between heat production and heat loss in ventilation. The maximum value of this difference can be computed, when the rate of the air flow and the heat production values are known, on the assumption that no heat is lost by radiation through the walls of the stable. It should, however, be borne in mind that it is only the heat eliminated by radiation and conduction that should be made the basis of the computation, since the latent heat of water vapor, as already explained, is not available for this purpose.

METHOD OF ESTIMATING THE TEMPERATURE DIFFERENCE

Assuming for the purpose of illustration an air movement corresponding on the one hand to King's standard and on the other hand to the amounts computed in Table XVII from the carbon-dioxide production, the temperature difference that can be maintained by the different animals can be determined in the following manner: One calorie of heat can raise the temperature of a pound of water about 4° F. Since the specific heat of air is 0.237 and since 100 cubic feet of air weigh 8 pounds, one calorie of heat can raise the temperature of 100 cubic feet of air

$\frac{4}{0.237 \times 8}$, or 2.1°. Consequently the heat required to warm by 1°

the daily volume of air per head required by King's standard or that computed in Table XVII from the carbon-dioxid production is:

Species.	By King's standard	By our estimates.
	Calories.	Calories.
Cows.....	405	394
Horses.....	492	264
Swine.....	159	88
Sheep.....	104	38

Supposing now that all the heat eliminated by the animals by radiation and conduction is imparted to the air passing into and out of the stable—that is, assuming that no heat is lost by radiation through the walls of the stable—this heat is capable of maintaining a temperature difference in degrees Fahrenheit equal to the daily heat emission per head by radiation and conduction divided by the figures of the foregoing table.

MAXIMUM TEMPERATURE DIFFERENCE MAINTAINED BY THE DIFFERENT SPECIES

By the method just described and by the use of the corresponding heat elimination values a calculation has been made of the maximum average difference in temperature between the stable and the outside air that can be maintained by the animal when King's (14) standards for ventilation or those computed from the carbon-dioxid production in Table XVII are used. This calculation is given in Table XVIII.

TABLE XVIII.—Average temperature difference maintained by animals

Species.	Average live weight.	Average temperature difference.	
		Corresponding to air flow computed by King.	Corresponding to air flow computed from carbon-dioxid production.
	Pounds.	°F.	°F.
Cows ^a	1,075	35.6	36.58
Horses.....	1,250	19.6	36.49
Swine.....	280	20.0	36.40
Sheep.....	91	13.3	36.50

^a The average heat emission by radiation and conduction by cows in milk were used for the computation.

On the basis of the average figures for the temperature difference given above, Table XIX has been computed, showing approximately the temperature of the stable when air enters at different temperatures,

first, at the rate recommended by King, and second, at the rate computed by the writers (Table XVII, columns 6 and 5, respectively).

TABLE XIX.—Temperature in stable as compared with that outside

Temperature of outside air.	Temperature of air in stable.				
	Corresponding to King's figures for ventilation.				Corresponding to air flow given in Table XVII, column 5.
	Cow.	Horse.	Swine.	Sheep.	All species.
°F.	°F.	°F.	°F.	°F.	°F.
-20	15.6	-0.4	0.1	-6.7	16.5
-10	25.6	9.6	10.1	3.3	26.5
0	35.6	19.6	20.1	13.3	36.5
10	45.6	29.6	30.1	23.3	46.5
15	50.6	34.6	35.1	28.3	51.5
20	55.6	39.6	40.1	33.3	56.5
25	60.6	44.6	45.1	38.3	61.5
30	65.6	49.6	50.1	43.3	66.5
35	70.6	54.6	55.1	48.3	71.5

This table is interesting in that it shows approximately the point at which the heat supplied by the animals becomes deficient for maintaining the proper temperature in the stable. Thus, when King's standard of air flow is taken as the minimum, the heat supplied by cows appears to become deficient for maintaining what is believed to be the best stable temperature when the outside temperature is below 15° F. The heat supplied by horses, swine, and sheep appears to become deficient at a much higher outside temperature. When, however, the rate of air flow computed from the carbon-dioxid production is made the basis of the computation, the differences between the species disappear.

MAXIMUM VENTILATION TO MAINTAIN A GIVEN TEMPERATURE DIFFERENCE

Conversely, the same data may be used to compute the maximum rate of air flow compatible with the maintenance of a given temperature difference between the stable and the air outside—for example, a stable temperature of 50° F. in zero weather—since it is evident that if the air flow be reduced the temperature difference and consequently the efficiency of the animals to warm the stable will be increased, while if the ventilation be increased the contrary will be the case. To illustrate this point Table XX has been computed, showing what rate of air movement would be required if it were desired to maintain a temperature difference of 50° between the stable and the outside air. It should be noted that, as in Tables XVIII and XIX, these are maximum values, since no allowance is made for losses of heat through the stable walls.

TABLE XX.—Maximum rate of air flow possible if a temperature difference of 50° F. is to be maintained

Species.	Average live weight.	Air flow per day per head.	Air flow per hour per head.
	Pounds.	Cubic feet.	Cubic feet.
Cows.....	1,075	60,530	2,522
Horses.....	1,250	40,459	1,686
Swine.....	280	13,453	561
Sheep.....	91	5,825	243

The results recorded in Table XX are notably lower than the minimum air flow computed in Table XVII as necessary to maintain the carbon-dioxid content of the stable air at 0.167 per cent and still further below the rate of air flow recommended by King. In other words (at least in the specific cases used as examples) it will be necessary in severe weather to restrict the ventilation in order to conserve heat and maintain a desirable stable temperature, and consequently the stable air will fall below King's standard of purity—namely, 0.167 per cent of carbon dioxid. The writers are not acquainted with any investigations upon the effects of a higher percentage of carbon dioxid upon animals during long periods, but in experiments with the respiration calorimeter this limit has frequently been exceeded in 2-day trials with no obvious ill effects.

Evidently there is a certain degree of discrepancy between King's requirements and the results of our computations. As has been mentioned on previous pages, the amount of carbon dioxid produced by animals is approximately proportional to their heat production, so that the rate of ventilation should also be approximately proportional to the heat production in order to maintain any desired standard or purity in the air of the stable. It is true that the heat production of animals may vary widely, but to the extent to which the examples we have used may be regarded as typical it appears that the accepted ventilation requirements for the different species are not proportional to their heat production. Taking the values for cows as unity, the relative computed heat production and King's relative ventilation requirements are approximately as follows:

Animal.	Relative heat production.	Relative air movement.
Cows.....	1.0	1.0
Heavy horses.....	.8	1.2
Swine.....	.2	.4
Sheep.....	.1	.3

Too much stress should not be laid on these differences, in view of the paucity of data for other species than cattle, but they indicate clearly the need for further fundamental investigation.

LITERATURE CITED

- (1) ARMSBY, Henry Prentiss.
1908. FEEDING FOR MEAT PRODUCTION. U. S. Dept. Agr. Bur. Anim. Indus. Bul. 108, 89 p., 1 fig.
- (2) ———
1912. THE MAINTENANCE RATIONS OF FARM ANIMALS. U. S. Dept. Agr. Bur. Anim. Indus. Bul. 143, 110 p., 1 fig.
- (3) ———
1917. THE NUTRITION OF FARM ANIMALS. xvii, 743 p., 45 fig. New York. Bibliographical footnotes.
- (4) ——— and FRIES, J. August.
1915. NET ENERGY VALUES OF FEEDING STUFFS FOR CATTLE. *In Jour. Agr. Research*, v. 3, no. 6, p. 435-491, 2 fig. Literature cited, p. 489-491.
- (5) ———
1916. NET ENERGY VALUES FOR RUMINANTS. Pa. Agr. Exp. Sta. Bul. 142, 20 p.
- (6) ——— and BRAMAN, Winfred Waite.
1920. THE CARBON DIOXIDE : HEAT RATIO IN CATTLE. *In Proc. Nat. Acad. Sci.*, v. 6, no. 5, p. 263-265.
- (7) BENEDICT, Francis G., and CARPENTER, Thorne M.
1910. THE METABOLISM AND ENERGY TRANSFORMATIONS OF HEALTHY MAN DURING REST. viii, 255 p. Washington, D. C. Carnegie Inst. Pub. 126.
- (8) CLARKSON, W. B., SMITH, L. J., and STRAHAN, J. L.
1920. REPORT OF COMMITTEE ON BARN VENTILATION. *In Trans. Amer. Soc. Agr. Engineers Rept.*, v. 13, 1919, p. 176-184, illus.
- (9) HACKEDORN, Howard.
1914. RATIONS FOR BREEDING EWES. Mo. Agr. Exp. Sta. Bul. 120, p. 31-57, illus.
- (10) HENRY, W. A., and MORRISON, F. B.
1915. FEEDS AND FEEDING. ed. 15, x, 691 p. Madison, Wis.
- (11) KELLNER, O., et al.
1896. UNTERSUCHUNGEN ÜBER DEN STOFF- UND ENERGIE-UMSATZ VOLLJÄHRIGER OCHSEN BEI ERHALTUNGSFUTTER. *In Landw. Vers. Stat.*, Bd. 47, p. 275-331.
- (12) ——— KÖHLER, A., et al.
1898. UNTERSUCHUNGEN ÜBER DEN NAHRUNGS- UND ENERGIE-BEDARF VOLLJÄHRIGER GEMÄSTETER OCHSEN. *In Landw. Vers. Stat.*, Bd. 50, Heft 3/4, p. 245-296.
- (13) ———
1900. UNTERSUCHUNGEN ÜBER DEN STOFF- UND ENERGIE-UMSATZ DES ERWACHSENEN RINDES BEI ERHALTUNGS- UND PRODUKTIONSFUTTER, AUSGEFÜHRT IN DEN JAHREN 1895-1899 AN DER KGL. LANDWIRTSCHAFTL. VERSUCHS-STATION ZU MÖCKERN. *Landw. Vers. Stat.*, Bd. 53, 474 p.
- (14) KING, F. H.
1908. VENTILATION FOR DWELLINGS, RURAL SCHOOLS, AND STABLES. 128 p., illus. Madison, Wis.
- (15) McCAMPBELL, C. W.
1912. FEEDING WORK HORSES. Kans. Agr. Exp. Sta. Bul. 186, p. 15-70, illus.

- (16) MEISSL, E.
1886. UNTERSUCHUNGEN ÜBER DEN STOFFWECHSEL DES SCHWEINES. *In Ztschr. Biol.*, Bd. 22 (N. F. Bd. 4), p. 63-160.
- (17) TANGL, Franz.
1912. DIE MINIMALE ERHALTUNGSARBEIT DES SCHWEINES (STOFF UND ENERGIEUMSATZ IM HUNGER). *In Biochem. Ztschr.*, Bd. 44, Heft 3/4, p. 252-278, 4 fig.
- (18) ZUNTZ, N., HAGEMANN, Oscar, et al.
1898. UNTERSUCHUNGEN ÜBER DEN STOFFWECHSEL DES PFERDES BEI RUHE UND ARBEIT. Neue Folge. *Landw. Jahrb.*, Bd. 27, Ergänzungsbd. 3, 438 p., 1 fig., 7 pl.

BULLETIN
OF THE
NATIONAL RESEARCH COUNCIL

Vol. 2. Part 4

JUNE, 1921

Number 12

COOPERATIVE EXPERIMENTS UPON THE PROTEIN
REQUIREMENTS FOR THE GROWTH OF CATTLE

First Report of the Subcommittee on Protein Metabolism
in Animal Feeding*

Presented for the Subcommittee by HENRY PRENTISS ARMSBY, Chairman

CONTENTS

Summary	219
Introduction	220
Plan for cooperative experiments on protein requirements for the growth of cattle	222
Investigations at the Massachusetts Agricultural Experiment Sta- tion, 1918	227
Investigations at the Massachusetts Experiment Station, 1919	239
Investigations at the Ohio State University	254
Investigations at the Virginia Experiment Station, 1918	257
Investigations at the Virginia Experiment Station, 1919	266
Discussion of results	274
The results of the metabolism trials	275
Live weights and measurements	285

SUMMARY

Cooperative experiments on a common plan have been made at three institutions, upon 26 animals in all, in which the effect upon the rate of growth of supplying different amounts of a substantially identical mixture of proteins in the daily rations of calves has been observed.

*Committee on Food and Nutrition, Division of Biology and Agriculture, National Research Council.

Digestion experiments and determinations of the gain of body protein (metabolism experiments) were carried out on 16 of the animals, the increase in height and girth was determined on 16 and the increase of live weight upon all.

The actual digestibility of the mixed rations proved to be less than that computed by the use of average digestion coefficients for the several constituent feeding stuffs. The difference was in general greater in the low-protein than in the high-protein rations, and greater for the protein than for the total feed (energy).

The accuracy of the determination of the gain of body protein appears to have suffered in some instances from the lack of opportunity to accustom the animals to the necessary experimental conditions.

Because of these irregularities, the results of the experiments, despite careful planning and most conscientious execution, must be considered as indicative rather than demonstrative, pending the results of additional experiments in progress at four other experiment stations. They constitute a reconnaissance rather than a complete survey of the field.

The results here reported seem to indicate that, with this particular protein mixture, a supply in the feed equal to the estimated maintenance requirement plus the normal increase in body protein is at least nearly sufficient to produce a normal gain of body protein and of live weight.

On the other hand, a more liberal supply of protein appears to have distinctly stimulated the rate of gain.

In the computation of rations in practice, using current average figures, it seems that an apparent surplus of 35% of digestible protein above the total of maintenance plus normal gain is sufficient to support a normal rate of growth provided other conditions are favorable, but that a larger allowance may result in a somewhat more rapid growth.

It appears reasonably clear that current feeding standards for growth call for a much greater supply of protein than is necessary to secure satisfactory results.

INTRODUCTION

In June, 1917, at the request of the Agriculture Committee of the National Research Council, the writer undertook to organize cooperative experiments upon some phase of the general question of the protein requirements of farm animals, especially as related to economy of food production during the war. Upon the reorganization of the Research Council in 1919 the Agriculture Committee was merged into the Section of Biology and Agriculture and the further prosecution of the experiments was referred

to a subcommittee of the Committee on Food and Nutrition, consisting of Pres. A. F. Woods of the University of Maryland, Dr. E. W. Allen, Director of the Office of Experiment Stations of the U. S. Department of Agriculture, and the writer as chairman.

The Agricultural experiment stations were the natural agencies to undertake such cooperation but the desirability of prompt action forbade any extensive consultation and since a uniform plan was essential to effective cooperation it was thought best to prepare one with the aid of such expert advice as was readily available. Accordingly a project was formulated for the study of the protein requirements for the growth of cattle, this question being one upon which the recorded results and opinions were far from harmonious and moreover one likely to be of economic importance not only during the war but in post-war reconstruction, while it was also of general scientific interest.

With the efficient cooperation of Dr. E. W. Allen this project was submitted to the directors of a selected list of experiment stations which it was believed would be particularly interested and their cooperation was solicited. Accompanying the plan was a letter of explanation from which the following paragraphs are quoted as explanatory of the spirit of the undertaking.

It is fully recognized that the greatest asset in an undertaking like this is the experience and trained judgment of the individual investigators participating and that these should be allowed the largest possible scope. On the other hand, however, a cooperative undertaking imposes certain unavoidable limitations. The object of cooperation is to secure a large number of results. This necessarily implies comparable experimental methods upon a common plan and a certain sacrifice of individuality.

In the preparation of the plan submitted herewith the endeavor has been to include only such points as appeared essential to effective cooperation. Even this, however, has involved a certain apparent assumption of authority, both as to method of attack and as to experimental details, since no extensive consultation has been practicable. Fortunately, I have been able to avail myself of the advice of some of the leading investigators in this general field and, while accepting full responsibility for the final plan, I desire to acknowledge my especial indebtedness to Dr. C. H. Eckles of the Missouri Experiment Station, Dr. H. S. Grindley of the Illinois Experiment Station, Professor E. B. Hart of the Wisconsin Experiment Station, Professor Lafayette B. Mendel of Yale University, Director F. B. Mumford of the Missouri Experiment Station and Dr. Thomas B. Osborne of the Connecticut Experiment Station.

Considerable interest in the project was expressed but the majority of the stations addressed found it impossible for various reasons to cooperate and up to the present time experiments have been undertaken by only seven stations, viz., those of Maryland, Massachusetts, Nebraska, North Dakota, Pennsylvania, South Dakota, and Virginia and by the Department of Animal Husbandry of the Ohio State University.

Experiments have been made in two successive years on substantially the same plan except that the protein supply of the low protein animals was increased somewhat in the second year. The plan was as follows:

PLAN FOR COOPERATIVE EXPERIMENTS ON PROTEIN REQUIREMENTS FOR THE GROWTH OF CATTLE

Statement of problem.—A productive ration must contain digestible protein at least equal to the maintenance requirement plus the amount of protein contained in the product.

Some recent investigations indicate that at least moderate production may be secured with rations containing but little more digestible protein than the minimum just indicated.

Other investigations, on the contrary, seem to show that a much more liberal protein supply is at least advantageous, if not necessary, and the current feeding standards for growing animals accord with this view.

In most of these investigations little or no attention has been paid to the quality of the proteins consumed, to the influence of accessory substances (vitamines), or to variations in the ash of the rations.

Method of attack.—The general idea is to feed either beef or dairy calves old enough to consume exclusive dry feed upon two different planes of protein intake but with equal net energy supply. The low-protein ration is to supply little more than the minimum amount theoretically required while the high-protein ration is to supply about the amount demanded by current feeding standards. The energy supply is intended to be such as will support normal growth but not cause material fattening.

The proteins of the two rations are to be derived in fixed proportions from identical feeding stuffs and an ample supply of ash ingredients and vitamins is to be assured. Any necessary adjustments in the bulk of the ration are to be made by variations in the amount of straw, and necessary adjustments of the energy supply by the use of greater or smaller amounts of commercial starch.

Animals.—Obviously the animals to be compared must be as nearly alike as possible. The plan contemplates the comparison of the animals by pairs, one animal of each pair receiving the high-protein and one the low-protein ration. The two animals of each pair should be of substantially the same breed (not necessarily full-bloods) and as nearly as possible of the same age and weight at the beginning of the experiment.

It is desired that as many pairs be used as is consistent with the keeping of individual records. Lot records are of far less value. The more nearly alike the several pairs are the better, but uniformity in this respect is not so essential as between the two animals of each pair.

It is desirable to select as young animals as can be expected to eat the proposed rations.

Feed requirements.—Rations are to be computed for different ages to furnish the amounts of digestible true protein and net energy per 1000 pounds live weight shown in the following table, age and not live weight being the controlling factor. The first column shows the theoretical minimum of digestible protein computed in the manner already indicated. It is proposed to increase this by about 35%* in the low-protein ration, in part to compensate for the probable depression of the digestibility, and to make the high-protein ration correspond substantially to Haecker's standards as reported in Henry and Morrison's "Feeds and Feeding," 15th Ed., p. 670. The estimates for net energy are those made by the writer. Figures for intermediate ages can be estimated with sufficient accuracy by interpolation.

*20% in the first year.

Estimated rations per 1000 lbs. live weight.
(To be computed in direct proportion to the live weight.)

Age	Estimated minimum of digestible protein	Digestible true protein of ration			Net energy
		Low		High	
		1st Year	2nd Year		
Months	Pounds	Pounds	Pounds	Pounds	Therms
4	1.50	1.80	2.03	3.00	18.0
5	1.30	1.56	1.76	2.70	16.1
6	1.20	1.44	1.62	2.40	14.5
9	1.00	1.20	1.35	2.10	12.7
12	0.85	1.00	1.15	2.00	11.8

Feeding stuffs.—It is proposed to supply proteins from a mixture of alfalfa hay, corn meal, linseed meal (O.P.) and high-grade peanut meal, as free from hulls as possible, in such proportions that the digestible true protein of the mixture will be supplied in the following proportions by the several feeding stuffs:

From alfalfa hay	30 per cent
From corn meal	10 per cent
From linseed meal (O.P.)	25 per cent
From peanut meal	33 per cent

100

It is believed that this will be a well-balanced protein mixture. These particular proportions have been selected because they seem to lend themselves well to the formulation of rations of the desired make up.

All computations are to be based on the so-called true protein, *i.e.*, crude protein minus non-protein, the non-protein being assumed to be entirely digestible. The factor 6.25 for protein is to be used throughout.

Quality of alfalfa hay.—One important function of the alfalfa hay in the ration is to supply basic ash ingredients and the accessory food substances.

In view of the very considerable variations in the quality of alfalfa hay care should be taken to secure a supply of good quality and especially one containing a normal proportion of leaves since these appear to be the principal carriers of ash and vitamins.

Rations.—To the foregoing mixture of feeding stuffs there is to be added sufficient oat straw and commercial starch to make up rations having the required protein content and energy value per 1000 lbs. Should it seem desirable, sugar may be substituted for part of the starch in amount sufficient to yield the same energy value. Simply as an illustration the following rations have been computed per 1000 pounds live weight for the age of six months on the assumption that the feeding stuffs have the composition and energy values shown in Bulletin No. 142 of the Pennsylvania Station, but using for corn meal the corrected net energy value of 85.20 Therms per 100 pounds reported in the *Journal of Agricultural Research*, v. 10, p. 612 (Sept. 17, 1918). Starch is estimated at 81.79 Therms, and sugar at 81.20 Therms per 100 lbs. dry matter.

High-protein ration	Dry matter	Digestible true protein	Net energy value
	lbs.	lbs.	Therms
10 lbs. Oat straw	8.85	0.08	3.48
10 lbs. Alfalfa hay (all analyses)	9.14	0.70	3.42
3.6 lbs. Corn meal	3.19	0.23	3.07
2.0 lbs. Linseed meal (O. P.)	1.82	0.57	1.78
2.0 lbs. Peanut meal	1.79	0.82	1.87
	24.79	2.40	13.62
1.27 lbs. Starch	1.08	....	0.88
	25.87	2.40	14.50

Low-protein ration*	Dry matter	Digestible true protein	Net energy value
	lbs.	lbs.	Therms
14 lbs. Oat straw	12.39	0.11	4.87
6.34 lbs. Alfalfa hay (all analyses)	5.79	0.45	2.17
2.34 lbs. Corn meal	2.08	0.15	1.99
1.35 lbs. Linseed meal (O. P.)	1.15	0.38	1.18
1.28 lbs. Peanut meal	1.14	0.53	1.20
	22.55	1.62	11.41
4.45 lbs. Starch	3.78	....	3.09
	26.33	1.62	14.50

The actual rations to be used should, however, be computed on the basis of the composition and estimated digestibility of the feeding stuffs actually used and should take account as far as possible of variations in the moisture content of the feeding stuffs.

Feeding.—It is contemplated that the proportions of the several feeding stuffs in the high protein and low protein rations respectively, computed in the manner just illustrated, shall be continued unchanged for the respective animals throughout the experiment. Amounts of these rations sufficient to supply the energy requirements per 1000 pounds live weight given in Table 1 for the different ages will furnish almost exactly the computed amounts of digestible protein required.

It is desirable to adjust the per head ration to the increasing live weight of the animal as frequently as seems practicable. In doing so, allowance should be made for the increase to be expected during the next interval. Thus if the ration is recalculated bi-weekly the new ration should be based on the live weight at the time of changing plus the increase to be expected during the following week.

*For the second year.

It is quite possible, however, that some modification of this plan may prove necessary. If the proportion of roughage in the rations proves to be too great, the quantity of oat straw may be reduced for both animals of a pair by the same amount per 1000 pounds live weight, disregarding the slight change in the protein thus caused or slightly increasing the amount of grain fed in order to keep the protein constant, while the starch is correspondingly decreased so as to keep the energy content unchanged.

It may be necessary also to adjust the energy supply of the animals in order, on the one hand to prevent fattening or on the other to maintain good condition. This may be effected by varying the amount of starch used, but the energy supply of both animals of a pair must be kept the same per 1000 pounds live weight.

Measurement of results.—By far the most satisfactory measure of the growth made is the amount of protein stored in the body as shown by the nitrogen balance of the animal. It is therefore urged that, if possible, the income and outgo of nitrogen be determined at intervals. This, of course, requires a quantitative collection of feces and urine and a determination of their nitrogen content. With male animals a separate collection of the two is not particularly difficult. With female animals it is believed that if necessary the two may be collected together and satisfactorily sampled, thus giving data for the nitrogen balance although not for the digestibility.

When a separate collection of the feces is made the data of the ordinary digestion experiment should be determined if practicable. This not only gives a control of the amount of digestible protein actually consumed but aids in estimating the actual energy values of the rations. If the heats of combustion of the feeds and excreta can be determined a still more accurate estimate is possible.

If determinations of the nitrogen balance are not possible, it is believed that useful, even if less accurate, conclusions may be derived from live weight results coupled with careful control of the general condition of the animals. In this case, however, it is especially important to avoid any material fattening, while at the same time maintaining what may be regarded as a good thrifty condition, by an adjustment of the energy supply in the way already indicated. The employment of as many animals as practicable tends to reduce the uncertainties of live weight experiments.

Systematic measurements of a few dimensions suitable for comparing the skeletal growth might aid greatly in the interpretation of the results.

Length of experiment.—It does not seem desirable to stipulate the duration of the experiment nor the frequency with which the digestibility and the nitrogen balance shall be determined. Obviously, the longer the experiment is continued and the more frequent the nitrogen balances or digestion trials, the more information may be hoped for. It is suggested that in the interest of securing results with reasonable promptness a total duration of five or six months may be the most desirable. It may be anticipated that the younger the animals the more decisive will be the results.

Summary.—The most essential requirements for successful cooperation in these experiments may be briefly summarized as follows:

1. Careful selection of animals as regards comparability.
2. All experimenters to use the same protein mixture in as nearly as possible the same relative amounts.
3. The animals to be compared must receive the same relative energy supply at the same age.
4. Growth is to be measured in terms of the nitrogen balance if possible; if not, in terms of live weight and dimensions.

A supplementary control.—If practicable, a useful check upon the results with the low-protein animals would be afforded by adding a third set of animals receiving the same low-protein ration but with skim milk substituted for linseed and peanut meals.

as a source of protein, the energy supply being adjusted by varying the amount of starch.

It is not desired, however, that this be undertaken to the detriment of the principal comparison.

Full reports have been prepared of two seasons' work at the Massachusetts and Virginia stations and of one season's at the Ohio State University. With the assent of the investigators at these institutions, this summary and discussion of the results has been prepared by the writer with the understanding that each institution is at liberty to publish as full a report of its own experiments as it may desire. It is hoped to discuss later the results obtained at the other cooperating stations.

RATE OF NORMAL GROWTH

These experiments were not intended to be simply a comparison of wide and narrow nutritive ratios but to be a contribution to our knowledge regarding the minimum amount of protein required to sustain normal growth.

In order to solve this problem, it is obviously necessary to have some standard of normal growth. The simplest and most obvious measure of growth is the increase in size and weight. But even when enough weighings are made to substantially eliminate the considerable fluctuations to which the daily weights of cattle are subject it is still possible that an actual increase of the structural elements of the body maybe, in part, either masked or exaggerated by a decrease or increase of the amount of body fat.

A method of measuring true growth which is, in principle, more accurate than weighing or measuring the animal consists in determining by means of a balance experiment the amount of nitrogen gained by the animal, since growth is essentially an increase of nitrogenous tissue. If the nitrogen balance can be determined without undue disturbance of the animal, it affords the most accurate measure of the rate of growth at a given date. but, as will appear later, it is not always easy to satisfy this condition. Both methods were used in these experiments.

Normal increase in weight.—The only extensive study of the normal rate of growth of cattle of which the writer is aware is that of Eckles¹ upon the normal growth of dairy cattle, the observations including the Holstein, Jersey, Ayrshire and Shorthorn breeds and being made upon over sixty animals in all. All the animals were females, while of the twenty-six animals used in the experiments here reported, twenty were males. In the absence, however, of any similar data for bull calves Eckles' averages have been used as a basis for comparison. For ages less than twelve months, as in these experiments, the error involved is probably not great.

Normal gain of protein.—The writer has brought together elsewhere² a

¹Missouri Experiment Station, Research Bulletin No. 36.

²U. S. Dept. Agr., Bur. Anim. Indus., Bul. 108 (1908), pp. 13-17: "The nutrition of Farm Animals," 1917, p. 375.

considerable number of data of more or less value regarding the rate of increase of protein in growth. Haecker's¹ determinations of the composition of the bodies of heavily fed cattle at different ages also afford results in general harmony with the others. With no attempt at the mathematical fitting of a curve to these results, it appears so far as can be judged by inspection alone, that the curve represented by the very simple equation

$$g = \frac{135}{a + 20}$$

in which a equals the age in days and g the gain of protein per thousand live weight, gives a very fair fit within the range of age included in these experiments.² This equation has been used in succeeding pages as a basis for estimating approximately the normal protein gains of the experimental animals as compared with those actually realized.

INVESTIGATIONS AT THE MASSACHUSETTS AGRICULTURAL EXPERIMENT STATION

By C. L. Beals under the general direction of J. B. Lindsey

EXPERIMENTS OF 1918

ANIMALS

Four pairs of calves were used in the experiments, as shown in Table 1, the experiment extending over 180 days.

PERIODS AND RATIONS

It was not found practicable to start Pair I on the same date as the others but each pair was fed, exclusive of a preliminary period of ten to twenty days, for 180 days sub-divided into six equal periods. The experiment with Pair I began on February 9th and that with other three pairs on January 10th.

The rations for each thirty-day period were computed in proportion to the live weight at the beginning of the period less an allowance of about ten pounds to assure complete consumption of the rations. The rations were intended to correspond with those prescribed in the plan, the computation of the protein and the net energy being based upon the average composition and

¹Proc. Soc. Anim. Prod., 1914, p. 18; Minn. Expt. Sta., Bul. 155, pp. 6-14, and private communication.

²It is obvious, of course, that at early ages it must give much too high values, the computed rate of gain at 20 days before birth being infinite.

energy values given in Bulletin 142 of the Pennsylvania Station but with allowance for the varying moisture content of the feeding stuffs as determined by analysis.

TABLE I
Description of animals

Pair	No.	Breed	Sex	Dropped 1917	Age in months at beginning of experiments	High or low protein ration	Initial weight in pounds
I	269	Ayrshire	Bull	Aug. 13	6	High	234
	270	Ayrshire	Bull	Sept. 14	5	Low	202
II	3	Holstein	Heifer	Aug. 1	5½	High	274
	4	Holstein	Heifer	July 24	6	Low	286
III	5	Holstein	Steer	June 1 ¹	6	High	260
	6	Holstein	Steer	June 1	6	Low	264
IV	7	Holstein	Steer	June 1 ¹	6	High	251
	8	Holstein	Steer	June 1	6	Low	267

DIGESTION AND METABOLISM TRIALS

One digestion and metabolism trial was made with Pair III and two with Pair IV, the excreta being collected for seven days following a 10-day preliminary period. It seems desirable to consider the results of these trials before taking up those upon live weight and size. Full details regarding the feeding are contained in the original report. The average daily rations of the high and low protein lots for the entire 180 days were:

	High protein		Low protein	
	Lbs.	Per cent	Lbs.	Per cent
Oat straw	3.01	37.08	3.86	48.50
Alfalfa Hay	2.88	34.45	1.49	18.72
Corn Meal	1.06	28.47	0.51	32.78
Linseed Meal	0.58		0.29	
Peanut Meal	0.52		0.27	
Starch	0.22		1.54	
	8.27	100.00	7.96	100.00

¹Approximate date.

Digestibility.—The following tables show the dates of the several digestion experiments, the weights of the nutrients digested and the percentage digestibility. As appears from the dates given, the digestion experiments fell in the sixth thirty-day period in the case of Pair III and in the fifth and sixth thirty-day periods for Pair IV. In these trials, the straw, hay and mixed grain (inclusive of the starch), but not the single grains, were analyzed except that the non-protein was not determined. The digestibility of the true protein has been computed by the writer on the assumption that the percentages of non-protein were the same as those shown in the table on p. 17 of Pennsylvania Bulletin No. 142 and that it was completely digested.

As appears from Table 2, the percentage digestibility of the protein was, as was to be expected, considerably lower in the low-protein than in high-protein rations while the digestibility of the crude fiber was also lower in two out of three cases. The digestibility of the nitrogen-free extract, on the other hand, tends to be somewhat higher in the low than in the high protein rations, owing doubtless to the considerable amount of starch which the former contained. This, however, is offset by the lower digestibility of the crude fiber, so that the digestibility of the total crude fiber + nitrogen-free extract shows an extreme range of only 2.6 in the case of Pair IV and of only 3.3 in the case of Pair III. In two cases out of the three the percentage digestibility of the total dry matter was less in the low-protein than in the high-protein ration by about 3.5 while in the third case the two were substantially equal.

On the other hand, however, the observed digestibility of the dry matter and protein of the mixed rations was distinctly lower than that computed from the actual composition of the feeding stuffs by the use of average digestion coefficients. From the data reported by the authors, using the coefficients given by Henry and Morrison¹ in their Table II, the results in Table 3 have been computed by the writer. In making these computations the digestibility of the crude protein of the grain mixture has been taken as the weighted mean of the coefficients for its several ingredients.

In the high protein rations the deficit in digestibility as compared with that computed is not very large, ranging from 5.4 to

¹"Feeds and Feeding," 15th Ed., page 647.

pounds live weight at the time of the digestion trials have been computed and compared with the amounts intended, with the results shown in Table 4. In this table the amounts of protein are computed from those per head shown in Table 2 while the net energy has been computed by the writer, in substantially the manner elsewhere¹ described by him, from the total dry matter and the digestible organic matter of the total rations, using the following estimated factors:

Metabolizable energy per gram digestible organic matter	3.7 Cals. ²
Heat increment per gram of total dry matter	1.15 Cals.

TABLE 4

Protein and energy supply per 1000 pounds live weight in digestion trials

	Pair IV June 5-11		Pair III June 19-25		Pair IV June 27-July 3	
	Digestible true protein	Net energy	Digestible true protein	Net energy	Digestible true protein	Net energy
	Lbs.	Therms	Lbs.	Therms	Lbs.	Therms
<i>High protein rations</i>						
Calf No. 5						
Intended			2.00	11.80		
Actual			1.74	8.84		
Calf No. 7						
Intended	2.03	12.10			2.00	11.80
Actual	1.80	8.53			1.73	8.72
<i>Low protein rations</i>						
Calf No. 6						
Intended			1.00	11.80		
Actual			0.84	7.26		
Calf No. 8						
Intended	1.07	12.10			1.00	11.80
Actual	0.98	8.62			0.70	7.52

¹"The Nutrition of Farm Animals," p. 674.

²Computed from Table 191, p. 649, of "The Nutrition of Farm Animals," assuming an average of 70% roughage and 30% grain in the rations. The result (3.7) agrees with figures of Table 192 of the same book.

The intended amounts of digestible protein and net energy in the foregoing table are those computed by the authors upon the live weights at the beginning of each trial by applying the data of Bulletin 142 of The Pennsylvania Station to the feeding stuffs used. They correspond, therefore, to the rations contemplated in the plan. Substantially the same results as regards net energy are also afforded by a computation like that made by the writer but based on the estimated instead of the actual digestible matter of the rations.

Gains of protein.—In these investigations the digestion trials included also the quantitative collection of the urine and the determination of the nitrogen balance. The corresponding daily gains of protein ($N \times 6.0$) per head and per 1000 pounds average live weight during each digestion trial are shown in Table 5. From these data it appears that the animal of each pair which received the high protein ration made a distinctly greater gain of protein than did its mate receiving the low protein ration. No corresponding data are available, of course, for the remainder of the experiments nor for the other animals.

TABLE 5
Daily gains of protein

	Pair IV June 5-11	Pair III June 19-25	Pair IV June 27-July 3
<i>High protein</i>			
Calf No. 5			
Per head		103.92 gm.	
Per 1000 lbs. live weight		0.57 lb.	
Calf No. 7			
Per head	58.68 gm.		86.64 gm.
Per 1000 lbs. live weight	0.35 lb.		0.48 lb.
<i>Low protein</i>			
Calf No. 6			
Per head		72.72 gm.	
Per 1000 lbs. live weight		0.41 lb.	
Calf No. 8*			
Per head	51.48 gm.		48.72 gm.
Per 1000 lbs. live weight	0.29 lb.		0.26 lb.

*The results for Calf No. 8 include an estimated correction for urine lost equivalent to 8.10 grams protein per head in the first trial and 1.04 grams in the second trial.

Before drawing conclusions as to the protein requirements of these animals, however, it must be considered that, owing to the relatively low digestibility as compared with that reckoned upon, all the animals, but particularly those on the low protein rations, consumed less energy than was contemplated. It appears desirable also to make such comparisons as are possible with the normal rate of increase of body protein at the several ages as estimated in the manner described in the introduction (p. 227).

TABLE 6
Protein supply and daily gains per 1000 pounds live weight

	Pair IV June 5-11 Age 372 days	Pair III June 19-25 Age 386 days	Pair IV June 27-July 3 Age 394 days
<i>High protein</i>	lbs.	lbs.	lbs.
Calf No. 5			
Digestible protein consumed		1.74	
Estimated maintenance requirement		0.50	
Available for growth		1.24	
Observed gain of protein		0.57	
Estimated normal gain		0.33	
Calf No. 7			
Digestible protein consumed	1.80		1.73
Estimated maintenance requirement	0.50		0.50
Available for growth	1.30		1.23
Observed gain of protein	0.35		0.48
Estimated normal gain	0.34		0.33
<i>Low protein</i>			
Calf No. 6			
Digestible protein consumed		0.84	
Estimated maintenance requirement		0.50	
Available for growth		0.34	
Observed gain of protein		0.41	
Estimated normal gain		0.33	
Calf No. 8			
Digestible protein consumed	0.98		0.70
Estimated maintenance requirement	0.50		0.50
Available for growth	0.48		0.20
Observed gain of protein	0.29		0.26
Estimated normal gain	0.34		0.33

In Table 6 the ages of the animals at the middle of the several digestion trials and the corresponding estimated normal gains of protein are compared with the actual gains of protein shown in Table 5, with the amounts of digestible protein in the rations (Table 4), and with the quantities available for growth after the estimated maintenance requirement was met, the latter being estimated at 0.50 lb. per 1000 pounds live weight (compare p. 276). In the case of Pair III, the calf receiving the low-protein ration (No. 6), which actually received only the minimum of protein estimated in the plan as necessary, appears from Table 6 to have made somewhat more than the normal gain of protein. His mate (No. 5), which received twice as much digestible protein, made a still greater gain of protein, some of which at least may be plausibly ascribed to the greater amount of net energy in his ration as computed in Table 4.

In the case of Pair IV, in the first digestion trial the animal receiving the low-protein ration (No. 8) received but slightly less digestible protein than was intended but made a gain distinctly below the estimated normal. Its mate, on the high-protein ration, with practically the same amount of net energy, made almost exactly the estimated normal gain. In the second digestion trial with the same pair, the low-protein animal (No. 8) received an amount of digestible protein decidedly below the estimated minimum, while the amount of net energy was also low. His gain fell materially below the normal while the high-protein animal of the pair, with much more net energy, made a gain considerably in excess of the normal.

Of course too much stress must not be laid on differences of a few hundredths of a pound of protein gained, yet on the whole the testimony of the nitrogen balances seems to indicate that the protein supply of the low-protein animals was scarcely sufficient to permit full utilization of their powers of growth but it at least suggests that a comparatively small increase of protein would have sufficed to do so.

It must be remembered, however, that, as shown in Table 4, the supply of net energy was much below that estimated to be required for normal growth and that this deficit is greater in the low-protein rations, averaging 35% as against 26% in the high protein rations. This deficiency may very well have tended to increase the rate of protein katabolism and thus to cut down the

rate of gain. On the other hand, however, the live weight results to be considered immediately hardly seem to indicate any great deficiency of net energy in the experiments as a whole.

INCREASE IN WEIGHT AND SIZE

Live weight.—The live weight of each animal was taken on two consecutive days at the beginning of the experiment and at the close of each 15 days. The increases per head in each successive interval and the cumulated increases are recorded in Table 7. Considerable fluctuation in the increase in successive intervals is to be noted, probably due in part to the weights being the average of only two weighings. The total gain by the high protein animal of each pair was greater than that of its mate on the low protein ration, both absolutely and in comparison with the initial live weight. Of the animals on which digestion trials were made,

TABLE 7

Gains in live weight

At end of	Pair I				Pair II			
	No. 269 High protein		No. 270 Low protein		No. 3 High protein		No. 4 Low protein	
	In 15 days	Cumu- lated	In 15 days	Cumu- lated	In 15 days	Cumu- lated	In 15 days	Cumu- lated
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
First 15 days	16.0	16.0	13.5	13.5	17.5	17.5	14.0	14.0
Second 15 days	11.0	27.0	10.0	23.5	16.0	33.5	7.0	21.0
Third 15 days	13.0	40.0	6.0	29.5	18.5	52.0	25.0	46.0
Fourth 15 days	17.0	57.0	12.5	42.0	19.0	71.0	8.0	54.0
Fifth 15 days	6.5	63.5	9.0	51.0	6.0	77.0	17.5	71.5
Sixth 15 days	7.5	71.0	11.5	62.5	19.5	96.5	4.0	75.5
Seventh 15 days	11.0	82.0	6.0	68.5	23.0	119.5	10.5	86.0
Eighth 15 days	31.5	113.5	16.0	84.5	-2.5	117.0	19.0	105.0
Ninth 15 days	22.5	136.0	17.5	102.0	14.0	131.0	3.0	108.0
Tenth 15 days	12.5	148.5	7.5	109.5	26.0	157.0	23.5	131.5
Eleventh 15 days	20.0	168.5	11.5	121.0	26.5	183.5	25.0	156.5
Twelfth 15 days	7.5	176.0	15.0	136.0	11.0	194.5	17.5	174.0

TABLE 7—(Continued)

At end of	Pair III				Pair IV			
	No. 5 High protein		No. 6 Low protein		No. 7 High protein		No. 8 Low protein	
	In 15 days	Cumu- lated	In 15 days	Cumu- lated	In 15 days	Cumu- lated	In 15 days	Cumu- lated
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
First 15 days	15.0	15.0	9.0	9.0	15.5	15.5	3.0	3.0
Second 15 days	0.0	15.0	6.5	15.5	4.5	20.0	14.0	17.0
Third 15 days	28.0	43.0	18.0	33.5	24.5	44.5	20.0	37.0
Fourth 15 days	19.0	62.0	22.0	55.5	10.0	54.5	6.5	43.5
Fifth 15 days	13.0	75.0	5.0	60.5	17.5	72.0	30.5	74.0
Sixth 15 days	18.5	93.5	14.0	74.5	11.0	83.0	9.0	83.0
Seventh 15 days	19.0	112.5	16.0	90.5	6.5	89.5	15.5	98.5
Eighth 15 days	5.0	117.5	-2.5	88.0	15.0	104.5	0.0	98.5
Ninth 15 days	-1.0	116.5	20.0	108.0	23.0	127.5	33.5	132.0
Tenth 15 days	28.5	145.0	25.0	133.0	12.0	139.5	5.5	137.5
Eleventh 15 days	13.0	158.0	13.5	146.5	18.5	158.0	22.0	159.5
Twelfth 15 days	23.5	181.5	15.0	161.5	29.0	187.0	16.5	176.0

No. 6 of Pair III, on the low protein ration, consumed rather less net energy than did its mate, No. 5, on the high protein ration, as appears from Table 4, this suggesting that the relatively lower gain in weight may be due in part to deficiency of energy. The same may also be said of No. 8 as compared with No. 7 (Pair IV) in the second digestion trial, but not in the first. The average gains per head by the two groups during the entire 180 days were as follows:

	Total	Per day	Percentage of initial live weight
	Lbs.	Lbs.	
High protein	184.75	1.03	72.5
Low protein	161.88	0.90	62.5

A comparison of the live weights of the calves with Eckles' growth curves of Holstein and Ayrshire heifers (page 226) is shown in Figure 1. It is apparent that these animals were lighter than those of the corresponding breeds observed by Eckles but that the rate of increase of the two Ayrshires was about the same while that of the six Holsteins was slightly less.

Height and girth.—The height and girth of each animal was measured at the times of weighing. The results as to increase in size correspond substantially with those on live weight, except that No. 6 on the low protein ration made a notably greater increase in height than did its mate, No. 5, on the high protein

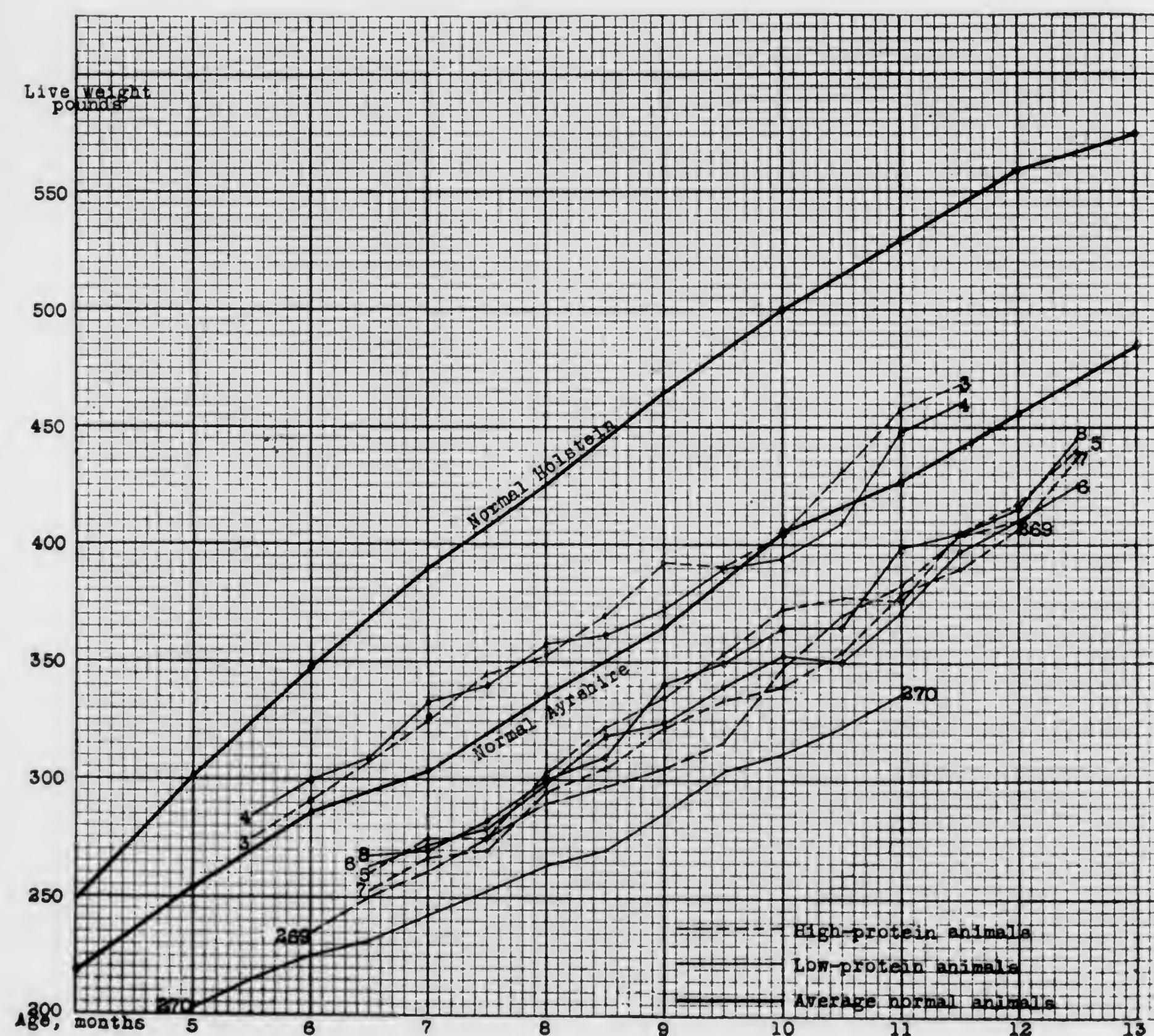


FIG. 1—Live weights of animals. Experiments conducted at the Massachusetts station in 1918. The numbers appearing at the ends of each curve in this figure refer to animals as numbered in Table 7.

ration, while, on the other hand, these two animals made almost identical increase of girth. The results regarding total increase for each animal and the means for the two groups are shown in Table 8.

TABLE 8
Total increase in height and girth

		Height in inches	Girth in inches
Pair I	No. 269 High protein	4.94	7.25
	No. 270 Low protein	4.00	6.13
Pair II	No. 3 High protein	6.81	8.63
	No. 4 Low protein	5.75	7.88
Pair III	No. 5 High protein	5.50	7.38
	No. 6 Low protein	6.31	7.25
Pair IV	No. 7 High protein	6.63	7.13
	No. 8 Low protein	6.63	7.13
Means	High protein	5.97	7.60
	Low protein	5.67	7.10

It would seem that the results upon increase in live weight and size confirm the conclusions drawn on page 235 from the nitrogen balances, namely, that the protein supply of the low protein animals was probably slightly below the minimum required for normal growth, while, as there stated, they do not indicate any material deficiency in the energy supply.

INVESTIGATIONS AT THE MASSACHUSETTS EXPERIMENT STATION (CONTINUED)

EXPERIMENTS OF 1919

The general plan for the experiments of 1919 was the same as in the previous year except that the protein supply of the low protein group, as explained on page 222, was to be increased 35% above the estimated minimum requirement instead of 20%.

ANIMALS

As in 1918, four pairs of calves were fed for 180 days upon the prescribed rations. The description of the animals is contained in Table 9.

TABLE 9

Description of animals

Pair	No.	Breed	Sex	Dropped 1918	Age in months at beginning of experiments	High or low protein ration	Initial weight in lbs.
I	19	Holstein	Heifer	Aug. 26	4	High	214.0
	18	Holstein	Heifer	July 31	5	Low	302.5
II	21	Holstein	Steer	Aug. 29	4	High	284.0
	20	Holstein	Steer	Aug. 20	4½	Low	288.5
III	23	Holstein	Steer	July 1	6	High	300.0
	22	Holstein	Steer	July 1	6	Low	292.5
IV	25	Holstein	Heifer	May 21	7½	High	326.5
	24	Holstein	Heifer	May 21	7½	Low	300.0

PERIODS AND RATIONS

After a preliminary period of 15 days, the experiment proper was begun on January 1, 1919, with all the animals, being divided into 12 periods of 15 days each.

The rations were computed to correspond with those prescribed in the plan as in 1918 except that the recalculations to allow for increased age and weight were made every 15 days instead of every 30 days. Full details of the daily rations are contained in the original report. The daily average rations per head for the entire 180 days were:

	High-protein Pounds	Low-protein Pounds
Oat straw	3.00	4.47
Alfalfa hay	3.16	3.05
Corn meal	1.20	0.81
Linseed meal	0.67	0.42
Peanut meal	0.62	0.39
Starch	0.37	1.67

DIGESTION AND METABOLISM EXPERIMENTS

Digestion and metabolism experiments were made with the animals of Pairs II and III in the even-numbered 15-day periods, viz., with Pair II (Nos. 20 and 21) in the 2d, 6th and 10th periods,

TABLE 10

Amount digested per day and head

	Weights digested		Percentage digestibility	
	No. 21 High-protein	No. 20 Low-protein	No. 21 High-protein	No. 20 Low-protein
	Grams	Grams	Per cent	Per cent
Pair II				
Period II				
January 25-31, incl.				
Dry matter	2154.95	2140.09	65.58	65.31
Ash	84.28	78.88	42.02	37.43
Crude protein	376.07	247.90	72.06	64.35
True protein	313.64	206.41	68.27	60.06
Crude fiber	358.37	365.01	47.87	49.06
Nitrogen-free extract	1263.28	1398.75	74.17	75.54
Ether extract	72.94	49.54	65.48	57.96
Fiber+N -fr. extract	1621.65	1763.76	66.13	67.96
Period VI				
March 26-April 1, incl.				
Dry matter	1951.40	2302.74	51.67	58.88
Ash	18.10	74.27	6.84	27.48
Crude protein	367.90	229.53	63.65	55.92
True protein	301.11	184.48	58.90	50.49
Crude fiber	272.67	385.70	31.34	42.55
Nitrogen-free extract	1217.95	1557.03	63.48	70.63
Ether extract	74.77	56.20	51.48	47.20
Fiber+N -fr. extract	1490.62	1942.73	53.45	62.44
Period X				
May 25-31, incl.				
Dry matter	2577.04	2511.28	60.32	57.08
Ash	156.73	79.64	45.09	25.24
Crude protein	485.25	270.88	72.28	57.64
True protein	412.91	224.64	68.94	53.02
Crude fiber	448.33	448.90	44.84	42.49
Nitrogen-free extract	1365.51	1629.65	65.73	67.44
Ether extract	122.23	82.22	69.13	58.18
Fiber+N -fr. extract	1813.84	2078.55	58.94	59.85

TABLE 10—(Continued)

	Weights digested		Percentage digestibility	
	No. 23 High-protein	No. 22 Low-protein	No. 23 High-protein	No. 22 Low-protein
	Grams	Grams	Per cent	Per cent
Pair III				
Period IV				
February 22-28, incl.				
Dry matter	2286.78	2208.03	62.16	63.17
Ash	82.80	59.41	33.46	24.60
Crude protein	359.56	196.53	68.68	58.14
True protein	294.66	156.22	64.24	52.47
Crude fiber	448.29	442.51	49.00	51.96
Nitrogen-free extract	1308.10	1449.01	70.57	74.01
Ether extract	88.03	60.55	63.21	56.71
Fiber + N.-fr. extract	1756.39	1891.52	63.44	67.33
Period VIII				
April 25-May 1, incl.				
Dry matter	2640.18	2401.36	61.78	61.53
Ash	100.45	71.47	38.38	32.67
Crude protein	443.52	252.34	71.62	59.59
True protein	369.94	207.83	67.79	54.72
Crude fiber	580.85	543.64	51.23	52.95
Nitrogen-free extract	1402.01	1480.88	66.91	69.64
Ether extract	113.36	62.73	68.17	53.65
Fiber + N.-fr. extract	1982.86	2024.52	61.40	64.21
Period XII				
June 24-30, incl.				
Dry matter	2560.93	2831.01	52.75	60.64
Ash	61.77	111.39	16.78	32.67
Crude protein	360.01	219.25	61.70	57.72
True protein	280.18	172.63	55.63	51.80
Crude fiber	622.62	693.03	45.54	54.97
Nitrogen-free extract	1415.99	1732.37	60.36	68.05
Ether extract	100.54	74.99	52.85	52.99
Fiber + N.-fr. extract	2038.61	2425.40	54.90	63.71

and with Pair III (Nos. 22 and 23), in the 4th, 8th and 12th periods. The quantitative collection of the excreta covered the last 7 days of the period, the first 8 days being regarded as preliminary. As in the previous year it seems desirable to consider first the results of the metabolism experiments.

Digestibility.—Table 10 shows the weights of the several nutrients digested and their percentage digestibility. The true protein was estimated, as in 1918, on the assumption that the feeding stuffs contained an average percentage of non-protein and that the latter was completely digested.

As in 1918, the digestibility of both the crude and true protein was considerably less in the low-protein than in the high-protein rations, the differences being of about the same order of magnitude as in the previous year. The digestibility of the crude fiber, on the other hand, with one exception (Period X), was greater in the low protein rations and the same is true without exception of the nitrogen-free extract and of the fiber + nitrogen-free extract. The digestibility of the ash and of the ether extract seems to follow that of the protein, being greater in the high-protein rations. Three of the trials, viz., Periods II, IV and VIII, show but slight differences in the digestibility of total dry matter, either as between the periods or between the high-protein and low-protein rations, corresponding in this respect with the results of 1918. In Periods VI, X and XII, however, the differences are more marked, the digestibility both of the dry matter and of all its ingredients, but especially of the ash and crude fiber, being relatively low. This is especially the case with the high-protein rations, particularly those of Calf No. 21, and suggests the influence of some abnormal condition.

As in the experiments of 1918, the observed digestibility of the dry matter and of the protein was less than that computed by the use of average digestion coefficients, as is shown in Table 11.

As regards the dry matter, the differences between the computed and observed digestibility are in general substantially the same in the high-protein and the low-protein rations while in the previous year they were greater in the low-protein rations. The differences may perhaps be ascribed to the relatively increased protein supply in the low-protein rations of 1919.

Exceptions to this statement, however, are to be noted in both animals in Period VI, with the high-protein animal in Period XII, and to a less degree with the low-protein animal in Period X, *i. e.*, in those periods whose results have already been queried.

As regards the total protein ($N \times 6.25$) the differences are greater in the low-protein than in the high-protein rations in both years. Here again, however, the differences in Periods VI, X and XII appear exceptionally large.

TABLE 11

Computed digestibility of dry matter and crude protein

	Dry matter		Crude protein	
	Observed	Computed	Observed	Computed
	Per cent	Per cent	Per cent	Per cent
Pair II				
Period II				
No. 21 High protein	65.58	70.70	72.06	75.70
No. 20 Low protein	65.31	70.99	64.35	70.34
Period VI				
No. 21 High protein	51.67	68.47	63.65	76.30
No. 20 Low protein	58.88	69.39	55.92	72.34
Period X				
No. 21 High protein	60.32	66.32	72.28	72.76
No. 20 Low protein	57.08	67.49	57.64	66.13
Pair III				
Period IV				
No. 23 High protein	62.16	68.62	68.68	76.07
No. 22 Low protein	63.17	69.33	58.14	70.92
Period VIII				
No. 23 High protein	61.78	66.36	71.62	73.74
No. 22 Low protein	61.53	67.41	59.59	69.22
Period XII				
No. 23 High protein	52.75	64.52	61.70	74.56
No. 22 Low protein	60.64	66.93	57.72	69.12

Metabolizable energy.—In addition to the determinations made in the experiments of the previous year, the heats of combustion of the feed, feces and urine were determined and that of the methane excreted was estimated from the amounts of digested crude fiber and nitrogen-free-extract, assuming the energy thus lost to be, for crude fiber 0.614 Cals. and for the nitrogen-free extract 0.422 Cals. per gram.¹ From these data, the differences between the income and outgo of chemical energy, *i. e.*, the metabolizable energy, were as shown in Tables 12 and 13.

¹Based on Kellner's results as reported by the writer in "Principles of Animal Nutrition," pp. 325 and 330.

TABLE 12

Metabolizable energy per head

	Pair III			Pair IV	
	High-protein No. 21	Low-protein No. 20		High-protein No. 23	Low-protein No. 22
	Cals.	Cals.		Cals.	Cals.
Period II	7944	7697	Period IV	8434	7732
Period VI	6743	7533	Period VIII	9487	8123
Period X	10152	8863	Period XII	8898	9348

TABLE 13

Metabolizable energy per 1000 pounds live weight

	Pair III			Pair IV	
	High-protein No. 21	Low-protein No. 20		High-protein No. 23	Low-protein No. 22
	Therms	Therms		Therms	Therms
Period II	25.63	23.75	Period IV	23.04	22.41
Period VI	17.11	19.17	Period VIII	21.51	19.02
Period X	21.41	19.02	Period XII	17.87	18.96

These amounts of metabolizable energy differ in some instances materially from those computed from the digested organic matter by the method followed in the experiments of 1918, being lower in two-thirds of the cases. The computation of the metabolizable energy per gram of digested organic matter likewise gives decidedly variable results, ranging from 3.4 cals. to 4.2 cals. The percentages of the gross energy of the feed which were metabolizable are shown in Table 14.

It will be noted that these results run more or less parallel with those upon digestibility already discussed and that apparently abnormal results are shown in the same periods.

Computed net energy.—If from the amounts of metabolizable energy shown in Table 12, there be subtracted the heat increment

TABLE 14

Percentage of gross energy metabolizable

	Pair III			Pair IV	
	High-protein No. 21	Low-protein No. 20		High-protein No. 23	Low-Protein No. 22
Period II	55.11	55.02	Period IV	51.57	51.14
Period VI	40.75	44.64	Period VIII	50.65	48.73
Period X	52.35	45.70	Period XII	42.02	47.58

due to the consumption of the feed, estimated as in the experiments of 1918 from the dry matter consumed, the computed net energy of the several rations was as recorded in Table 15.

TABLE 15

Computed net energy per head

	Pair III			Pair IV	
	High-protein No. 21	Low-protein No. 20		High-protein No. 23	Low-protein No. 22
	Cals.	Cals.		Cals.	Cals.
Period II	4165	3928	Period IV	4203	3712
Period VI	2400	3035	Period VIII	4572	3635
Period X	5239	3803	Period XII	3315	3979

Intended and actual feed supply.—From the foregoing data and the average live weights for the first two and last two days of each digestion trial, the digestible true protein and net energy of the rations consumed per 1000 lbs. live weight in the digestion trials have been computed and compared with the amounts intended to be consumed, with the results shown in Table 16. In this table the amounts of protein are computed from those per head shown in Table 10, and those of net energy from those given in Table 15.

TABLE 16
Protein and energy supply per 1000 pounds live weight

	Pair II		Pair III	
	High-protein No. 21	Low-protein No. 20	High-protein No. 23	Low-protein No. 22
Period II Intended Actual	Protein Lbs.	2.55 2.23	Protein Lbs.	1.48 1.00
	Energy Therms	15.30 13.44	Energy Therms	13.60 11.48
Period VI Intended Actual	Protein Lbs.	2.25 1.69	Protein Lbs.	1.32 1.07
	Energy Therms	13.60 6.09	Energy Therms	12.55 10.37
Period X Intended Actual	Protein Lbs.	2.08 1.92	Protein Lbs.	1.18 0.77
	Energy Therms	12.55 11.05	Energy Therms	11.95 8.66
Period IV Intended Actual				
Period VIII Intended Actual				
Period XII Intended Actual				

As in 1918, the actual feed supply as computed from the results of the digestion periods was less than was intended, owing chiefly to the differences in digestibility shown on page 244. In this year, with the relatively greater protein supply to the low-protein animals, no marked superiority in this respect of the high-protein rations over the low-protein ones was observed. The deficit was notably greater in those cases, already noted, in which the digestibility of the rations as a whole appears to have been abnormally low.

Gains of protein.—Small losses of urine occurred in five of the metabolism trials, the error thus caused being estimated by the authors at from 0.06 grams to 2.26 grams of nitrogen. Including these corrections, the daily gains of protein ($N \times 6.0$) in each metabolism experiment, per head and per 1000 lbs. average live weight during the experiment, were as shown in Table 17.

TABLE 17
Daily gains of protein

Pair II			Pair III		
	No. 21 High- protein	No. 20 Low- protein		No. 23 High- protein	No. 22 Low- protein
Period II			Period IV		
Per head. Grms.	+69.24	+94.08	Per head. Grms.	+74.16	+30.36
Per 1000 live weight	+0.49	+0.64	Per 1000 live weight	+0.45	+0.19
Period VI			Period VIII		
Per head. Grms.	-76.62	-106.80	Per head. Grms.	+122.64	+41.16
Per 1000 live weight	-0.43	-0.60	Per 1000 live weight	+0.61	+0.21
Period X			Period XII		
Per head. Grms.	+178.20	-11.22	Per head. Grms.	-59.16	+41.46
Per 1000 live weight	+0.84	-0.05	Per 1000 live weight	-0.26	+0.19

The striking feature of these results is the marked irregularity of the nitrogen balance, some of the periods even showing a loss of protein, which appears unlikely in growing animals. It will be noted that these negative nitrogen balances occur in those periods in which the digestion results seem abnormal but the apparent

TABLE 18
Protein supply and daily gains per 1000 pounds live weight

Pair II			Pair III		
	No. 21 High- protein	No. 20 Low- protein		No. 23 High- protein	No. 22 Low- protein
Period II	Age 152 days	Age 161 days	Period IV	Age 239 days	Age 239 days
Digestible protein consumed	Lbs.	Lbs.	Digestible protein consumed	Lbs.	Lbs.
Estimated maintenance requirement	2.23	1.40	Estimated maintenance requirement	1.78	1.00
Available for growth	0.50	0.50	Available for growth	0.50	0.50
Observed gain of protein	1.73	0.90	Observed gain of protein	1.28	0.50
Estimated normal gain	0.49	0.64	Estimated normal gain	0.45	0.19
Period VI	Age 212 days	Age 221 days	Period VIII	Age 301 days	Age 301 days
Digestible protein consumed	Lbs.	Lbs.	Digestible protein consumed	Lbs.	Lbs.
Estimated maintenance requirement	1.69	1.04	Estimated maintenance requirement	1.85	1.07
Available for growth	0.50	0.50	Available for growth	0.50	0.50
Observed gain of protein	1.19	0.54	Observed gain of protein	1.35	0.57
Estimated normal gain	-0.43	-0.60	Estimated normal gain	0.61	0.21
Period X	Age 272 days	Age 281 days	Period XII	Age 361 days	Age 361 days
Digestible protein consumed	Lbs.	Lbs.	Digestible protein consumed	Lbs.	Lbs.
Estimated maintenance requirement	1.92	1.06	Estimated maintenance requirement	1.24	0.77
Available for growth	0.50	0.50	Available for growth	0.50	0.50
Observed gain of protein	1.42	0.56	Observed gain of protein	0.74	0.27
Estimated normal gain	0.84	-0.05	Estimated normal gain	-0.26	0.19
	0.46	0.45		0.35	0.35

decrease in digestibility (or, in other words, the increased excretion of nitrogen in the feces) is insufficient to account for the negative nitrogen balance.

In Table 18, the actual gains of protein per day per 1000 pounds live weight shown by the metabolism experiments and the estimated normal gains at the several ages are compared with the amounts of digestible protein supplied (Table 16) and with the amounts available for growth after deducting the estimated maintenance requirement.

The remarkable fluctuations of the nitrogen balances, and particularly the negative balances, as well as the peculiar results regarding digestibility, in these trials, render the interpretation of the experiment difficult. One is tempted to disregard the four periods which show an apparent loss of body protein, particularly since the authors are inclined to ascribe the seemingly erratic results to the fact that the animals, in the absence of previous training, became somewhat nervous when placed in the elevated stalls and sometimes actually lost a few pounds in weight which was rapidly made up after their removal. If this be done, even although no specific justification for it appears in the recorded figures, the following comparisons of the feed supply and the gain of protein by the animals in the remaining periods may be made.

Range of protein supply in percentage of estimated minimum requirement	
High-protein rations	173% to 201%
Low-protein rations	91% to 116%
Range of energy supply in percentage of estimated requirement	
High-protein rations	79% to 88%
Low-protein rations	68% to 84%
Range of gain of protein in percentage of estimated normal gain	
High-protein rations	62% to 183%
Low-protein rations	37% to 85%

These selected results would seem to indicate that the protein supply in the low-protein rations was insufficient to support normal gains, while in several of the high-protein rations the surplus protein would seem to have stimulated growth in excess of the normal. It does not seem that the inferior results on the low-protein rations were due to lack of energy.

Such conclusions, however, are in conflict with these drawn from the live weights and measurements of the animals as reported in the following paragraphs.

INCREASE IN WEIGHT AND SIZE

Live weight.—As in 1918, the live weights were taken each 15 days upon two consecutive days. The increases per head and the cumulated increases are recorded in Table 19.

A fairly steady rate of growth was maintained by all the animals. The increase by the high-protein animal of Pair I (No. 19) and that by the low-protein animal of Pair IV (No. 24) was distinctly less than that made by the others but the percentage gain by No. 19 was relatively high. These somewhat small gains, however, offset each other, so that the absolute gains of the high-protein and low-protein lots as a whole were practically the same, but the percentage gain by the high-protein group was slightly

TABLE 19

Gains in live weight

At end of		Pair I				Pair II			
		No. 19 High-protein		No. 18 Low-protein		No. 21 High-protein		No. 20 Low-protein	
		In 15 days	Cumu- lated	In 15 days	Cumu- lated	In 15 days	Cumu- lated	In 15 days	Cumu- lated
		Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
First	15 days	11.5	11.5	18.5	18.5	17.0	17.0	23.0	23.0
Second	15 days	19.5	31.0	13.0	31.5	6.0	23.0	11.5	34.5
Third	15 days	8.5	39.5	14.0	45.5	30.5	53.5	14.5	49.0
Fourth	15 days	11.5	51.0	21.0	66.5	13.5	67.0	18.5	67.5
Fifth	15 days	15.0	66.0	13.0	79.5	23.0	90.0	21.5	89.0
Sixth	15 days	19.0	85.0	30.5	110.0	17.5	107.5	21.5	110.5
Seventh	15 days	13.5	98.5	11.0	121.0	21.0	128.5	13.5	124.0
Eighth	15 days	8.5	107.0	19.0	140.0	22.5	151.0	17.5	141.5
Ninth	15 days	27.0	134.0	27.5	167.5	35.0	186.0	32.5	174.0
Tenth	15 days	14.5	148.5	20.0	187.5	5.0	191.0	2.5	176.5
Eleventh	15 days	-2.5	146.0	7.5	195.0	20.0	211.0	35.0	211.5
Twelfth	15 days	25.0	171.0	22.5	217.5	17.5	228.5	15.0	226.5

TABLE 19—(Continued)

At end of		Pair III				Pair IV			
		No. 23 High-protein		No. 22 Low-protein		No. 25 High-protein		No. 24 Low-protein	
		In 15 days	Cumu- lated	In 15 days	Cumu- lated	In 15 days	Cumu- lated	In 15 days	Cumu- lated
		Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
First	15 days	16.5	16.5	12.0	12.0	18.5	18.5	13.0	13.0
Second	15 days	27.5	44.0	10.0	22.0	16.0	34.5	18.5	31.5
Third	15 days	13.5	57.5	23.0	45.0	9.0	43.5	7.5	39.0
Fourth	15 days	18.5	76.0	17.5	62.5	21.0	64.5	26.0	65.0
Fifth	15 days	16.5	92.5	14.0	76.5	13.5	78.0	5.0	70.0
Sixth	15 days	31.0	123.5	33.5	110.0	29.5	107.5	35.0	105.0
Seventh	15 days	11.5	135.0	15.0	125.0	13.5	121.0	1.5	106.5
Eighth	15 days	11.5	146.5	24.0	149.0	11.5	132.5	11.0	117.5
Ninth	15 days	37.5	184.0	28.5	177.5	40.0	172.5	25.0	142.5
Tenth	15 days	26.0	210.0	20.0	197.5	16.0	188.5	30.0	172.5
Eleventh	15 days	-10.0	200.0	0.0	197.5	5.0	193.5	-20.0	152.5
Twelfth	15 days	12.5	212.5	10.0	207.5	27.5	221.0	17.5	170.0

the greater. The mean gains per head by the two groups during the entire 180 days were practically identical, viz.,

	Total Lbs.	Per day Lbs.	Percentage of initial live weight
High-protein	208.5	1.16	74.1
Low-protein	207.5	1.14	69.1

The graph of the live weights of the animals (Fig. 2) likewise fails to show any consistent difference between the high-protein and the low-protein animals as regards rate of growth. The rate of growth also corresponds substantially with Eckles' results although the actual live weights were somewhat lower.

Height and girth.—Curiously, the greater total increase in size in these experiments was made by the low-protein animals. This is true either of the height or girth in each pair and of both in Pair III and on the average of the entire lots, as Table 20 shows. No obvious explanation of this peculiar result suggests itself.

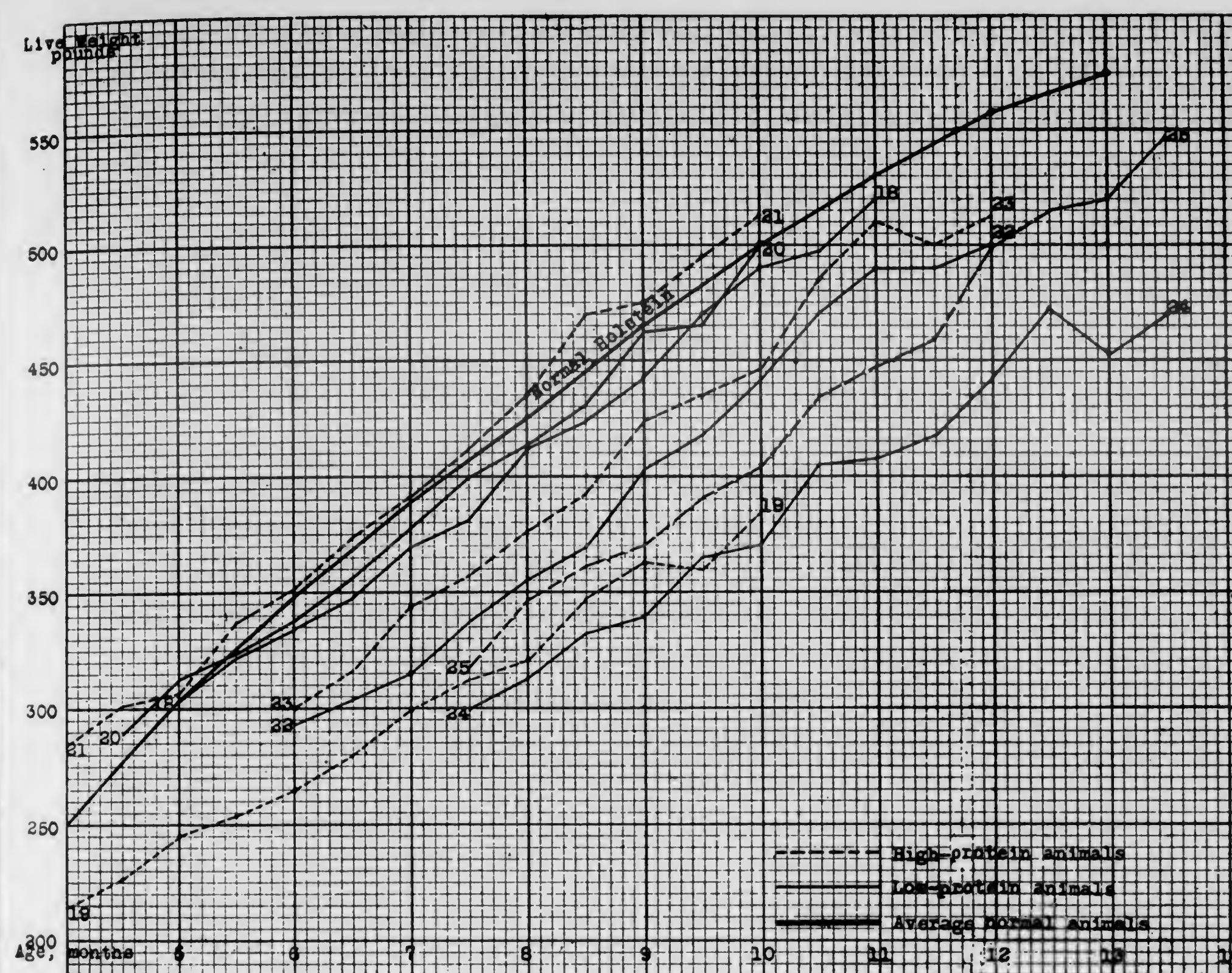


FIG. 2.—Live weights of animals. Experiments conducted at the Massachusetts station in 1919. The numbers appearing at the ends of curves in this figure refer to animals as numbered in Table 19.

TABLE 20
Total increase

		Height in inches	Girth in inches
Pair I	No. 19 High protein	6.5	9.0
	No. 18 Low protein	6.5	10.9
Pair II	No. 21 High protein	7.4	10.6
	No. 20 Low protein	7.5	11.0
Pair III	No. 23 High protein	5.9	9.0
	No. 22 Low protein	7.0	10.3
Pair IV	No. 25 High protein	5.4	9.0
	No. 24 Low protein	7.0	8.3
Means	High protein	6.3	9.4
	Low protein	7.0	10.1

In view of these very decided results regarding the increase in weight and size, and of the uncertainty attaching to the nitrogen balances, the conclusion seems justified that the relatively small protein supply in the low-protein rations was at least nearly sufficient to support normal growth.

INVESTIGATIONS AT THE OHIO STATE UNIVERSITY

By C. S. Plumb, C. T. Conklin and J. F. Lyman

The animals used in these experiments were two grade Shorthorns, six months of age, both thin, although in thrifty condition. Before putting the animals on feed they were subjected to the tuberculin test and were passed with a clean bill of health. The experiments covered 77 days, viz., March 9th to May 24th, 1918, inclusive. On account of the war situation, resulting in delayed shipment of materials and depletion of the staff by draft or enlistment, it was found impossible to continue the experiments for a longer time or with a larger number of animals or to conduct digestion and metabolism experiments.

The feeding stuffs used were all analyzed, including the determination of the non-protein. Their content of digestible nutrients was computed by the use of Henry and Morrison's digestion coefficients and their net energy estimated from these results by the method described in Bulletin No. 142 of the Pennsylvania Experiment Station. As thus computed, the average daily consumption of digestible protein and net energy per head and per 1000 pounds mean live weight during the experiment was as shown in Table 21. Upon these rations the two animals made identical gains in live weight, as Table 22 shows.

TABLE 21
Computed rations

	Digestible protein		Net energy	
	Per head	Per 1000 lbs. live weight	Per head	Per 1000 lbs. live weight
	Lbs.	Lbs.	Therms	Therms
Low protein	0.52	1.31	5.37	13.5
High protein	0.87	2.10	5.52	13.3

TABLE 22
Summary of gains

	High-protein	Low-protein	Eckles Shorthorn Heifers
Weight of calves March 9th	344 lbs.	328 lbs.	316 lbs.
Weight of calves May 24th	485 lbs.	469 lbs.	440 lbs.
Gain in weight	141 lbs.	141 lbs.	124 lbs.
Per cent of initial weight	41%	43%	
No. of days fed	77 days	77 days	
Average daily gain	1.83 lbs.	1.83 lbs.	1.61 lbs.

The rate of gain of the two animals was materially greater than that observed by Eckles for Shorthorn heifers of the same age. It would appear, therefore, that the low-protein ration contained sufficient protein so that the latter was not a limiting factor in growth.

The amounts of digestible protein computed to have been consumed compare as follows with the estimated minimum requirements per 1000 pounds live weight for animals of this age.

TABLE 23
Comparison with minimum requirement

	High-protein Lbs.	Low-protein Lbs.
Maintenance requirement	0.50	0.50
Estimated normal gain	0.56	0.56
Total minimum requirement	1.06	1.06
Computed digestible	2.10	1.31

These figures make it appear that even the low-protein animal received a considerable surplus of protein. The digestion experiments on similar rations at the Massachusetts and Virginia stations reported elsewhere in this paper, however, show that the digestibility of the protein was lower than was anticipated, al-

though by widely varying amounts. The deficit in the high-protein rations varied from 8 to 33 per cent and that in the low-protein rations from 8 to 49 per cent. Omitting the highest and lowest figures in each case, the range was from 11 to 29 per cent with the high-protein rations and from 16 to 48 per cent with the low-protein. Omitting some questionable results (page 250), the mean deficit was 20 per cent and 24 per cent respectively. Even a deficit of 16 per cent in digestibility in the low-protein ration of this experiment, however, would reduce the protein supply to about the estimated minimum. While too much weight must not be given to such comparisons, they nevertheless tend to strengthen the conclusion that a protein supply but little in excess of the estimated minimum requirement sufficed to support a normal rate of growth.

INVESTIGATIONS AT THE VIRGINIA EXPERIMENT STATION

By C. W. Holdaway, W. B. Ellett and W. G. Harris

EXPERIMENTS OF 1918

ANIMALS

The animals used in this experiment were grade Holstein steers rather poorly developed for their age, their weights being considerably below the averages reported by Eckles (p. 226) for Holstein heifers. Nos. 72 and 73 did not appear as thrifty as the others and were therefore placed in different groups. No grouping by pairs is reported. The ages and initial weights of the animals were as follows:

TABLE 24

Ages and weights

Ration	No.	Initial age Months	Initial weight Pounds
High-protein	No. 71	8	213
	No. 72	8	195
Low-protein	No. 73	9	230
	No. 74	9	240

PERIODS AND RATIONS

The experiment was divided into two periods, following a preliminary feeding from March 1 to 25, 1918. The first experimental period extended from March 25, 1918, to June 30, 1918, or 97 days, and the second period from July 1, 1918, to September 25, 1918, or 87 days.

The rations for the first period were computed on the basis of the ages and live weights given above to correspond with the directions. Computed per 1000 pounds live weight they corresponded approximately with the age of the animals. (Table 25.) On July 1, 1918, the rations were changed to meet the estimated requirements of increased age and weight, the rations being com-

TABLE 25
Daily rations of first period

	High-protein		Low-protein	
	Calf No. 71	Calf No. 72	Calf No. 73	Calf No. 74
Age	8 Months	8 Months	9 Months	9 Months
Initial live weight	213 lbs.	195 lbs.	230 lbs.	240 lbs.
<i>Rations per head, grams</i>				
Oat s raw	580	531	1252	1306
Alfalfa hay	1237	1132	696	725
Maize Meal	338	310	190	198
Linseed meal	181	165	101	106
Peanut meal	214	196	120	125
Starch	56	51	351	366

puted to correspond to the ages and weights on that date. Per head the rations were as shown in Table 26.

TABLE 26
Daily rations of second period

	High-protein		Low-protein	
	Calf No. 71	Calf No. 72	Calf No. 73	Calf No. 74
Age	11 Months	11 Months	12 Months	12 Months
Initial live weight	260 lbs.	225 lbs.	260 lbs.	270 lbs.
<i>Rations per head, grams</i>				
Oat straw	708	612	1416	1470
Alfalfa hay	1398	1210	646	670
Maize meal	382	330	176	184
Linseed meal	204	176	94	98
Peanut meal	240	208	110	116
Starch	90	78	574	596

DIGESTION AND METABOLISM EXPERIMENTS

During each of the two periods the digestibility of the total ration and the nitrogen balance were determined for each animal, the excreta being collected quantitatively for six days, viz., in the first period May 16-21 inclusive and in the second period Sept. 6-11 inclusive.

Digestibility.—Table 27 shows the actual weights of the several nutrients digested per day and per head together with the digestion coefficients.

TABLE 27
Amount digested per day and head

	High-protein				Low-protein			
	Calf No. 71		Calf No. 72		Calf No. 73		Calf No. 74	
	1st trial	2d trial	1st trial	2d trial	1st trial	2d trial	1st trial	2d trial
<i>Weights digested Grams</i>								
Dry matter	1537.6	1783.3	1324.7	1442.9	1500.7	1751.2	1594.8	1799.1
Organic matter	1473.2	1746.8	1268.6	1426.0	1447.2	1707.9	1537.3	1762.1
Crude protein	243.5	280.3	221.6	235.5	124.9	118.1	128.5	113.1
True protein	191.3	221.2	173.8	184.3	93.7	83.6	95.9	82.5
Crude fiber	365.3	424.6	303.0	374.2	432.5	459.6	459.0	435.1
Nitrogen-free extract	815.2	981.3	701.0	765.7	853.4	1092.8	905.3	1169.4
Ether extract	49.2	60.6	43.0	50.6	36.4	42.4	44.5	44.5
<i>Per cent digested</i>								
Dry matter	67.5	66.2	63.7	61.9	62.7	65.2	63.9	64.4
Organic matter	69.6	69.7	65.6	65.8	64.2	67.2	65.4	66.7
Crude protein	70.7	70.9	70.4	68.8	55.8	53.9	55.0	49.5
True protein	65.5	65.8	65.1	63.4	48.6	44.1	47.7	41.7
Crude fiber	56.4	55.4	51.3	56.4	60.4	59.7	61.6	54.5
Nitrogen-free extract	77.0	77.5	72.5	69.9	68.0	73.3	69.2	75.5
Ether extract	74.8	79.8	71.5	77.0	61.5	69.3	72.1	69.8

The digestion coefficients show that there was a marked depression of the digestibility of the protein in the low-protein rations which resulted in lowering the protein supply below the amount

intended to be fed. Differences also appear in the digestibility of the crude fiber and nitrogen-free extract, the digestibility of the former being greater and that of the latter less in the low-protein rations in both trials, although the difference was not so marked in the second trial. It would seem that these differences are due chiefly to differences in the proportions of the different feeding stuffs consumed. On the other hand the digestibility of the total crude fiber plus nitrogen-free extract (carbohydrates) and of the total dry matter shows but slight differences.

As in the Massachusetts experiments, a comparison of the observed digestibility of the dry matter and crude protein of the rations with that computed by the use of average coefficients, as recorded in Table 28, reveals the fact that in every instance the observed digestibility of the crude protein is less than the computed, the difference in the percentage rising as high as 19 in one instance, and that the same thing is true to a lesser extent of the digestibility of the dry matter except in the case of Calf No. 71.

TABLE 28

Observed and computed digestibility of dry matter and crude protein

	Dry matter		Crude protein	
	Observed Per cent	Computed Per cent	Observed Per cent	Computed Per cent
<i>First period</i>				
High-protein				
No. 71	67.5	66.2	70.7	76.9
No. 72	63.7	66.2	70.4	76.9
Low-protein				
No. 73	62.7	66.0	55.8	70.6
No. 74	63.9	66.0	55.0	70.6
<i>Second period</i>				
High-protein				
No. 71	66.2	66.3	70.9	76.5
No. 72	61.9	66.3	68.8	76.5
Low-protein				
No. 73	65.2	67.7	53.9	68.9
No. 74	64.4	67.7	49.5	69.5

In the high-protein rations the apparent deficit in digestibility is slight, ranging from 0.1 to 4.4 for the dry matter and from 5.6 to 7.7 for the crude protein. In the low-protein rations, the deficit is not materially greater for the dry matter (2.1 to 3.3) but strikingly greater for the crude protein (14.8 to 20.0). For this reason, and also because the rations were computed on the initial weights in each period, the amounts of digestible protein and of net energy supplied to the animals per 1000 pounds live weight in the actual digestion trials were less than were intended, especially with the low-protein animals.

TABLE 29

Protein and energy supply per 1000 pounds live weight in digestion trials

	First trial		Second trial	
	Digestible true protein Lbs.	Net energy Therms	Digestible true protein Lbs.	Net energy Therms
<i>High-protein</i>				
Calf No. 71				
Intended	2.20	13.30	2.03	12.10
Observed	1.67	{ 10.69 ¹ 11.24 ²	1.73	{ 11.25 ¹ 11.96 ²
Calf No. 72				
Intended	2.20	13.30	2.03	12.10
Observed	1.75	{ 11.24 ¹ 10.50 ²	1.65	{ 11.10 ¹ 10.52 ²
<i>Low-protein</i>				
Calf No. 73				
Intended	1.20	12.71	1.00	11.80
Observed	0.80	{ 10.35 ¹ 10.08 ²	0.66	{ 10.99 ¹ 11.59 ²
Calf No. 74				
Intended	1.20	12.71	1.00	11.80
Observed	0.78	{ 10.33 ¹ 10.45 ²	0.62	{ 10.80 ¹ 11.24 ²

¹As computed by the authors.

²As computed by the writer.

Intended and actual feed supply.—As already stated, the rations were intended to correspond to those proposed in the plan. In computing the rations the average coefficients reported by Henry & Morrison¹ were applied to the results of the analyses of the feeding stuffs. The digestibility of the true protein was estimated by deducting from the computed digestible crude protein the total amount of non-protein as reported in Bulletin No. 142 of the Pennsylvania Experiment Station. The net energy for the preliminary period was calculated from the data of the same Bulletin, allowing for differences in moisture content. For the rations of both digestion periods it was computed from the composition of the single feeding stuffs, by the use (apparently) of average digestion coefficients, by the method proposed by the writer. The writer has also computed the net energy from the total digestible organic matter of the rations as found in the digestion trials, using the same method as in the Massachusetts experiments (p. 232). The results are shown in Table 29.

Gains of protein.—In the digestion trials, the urine of the animals was also collected quantitatively and its nitrogen determined, thus giving the nitrogen balance and the gain of protein. Assuming the results of the digestion and metabolism trials to be representative, and computing the results per 1000 pounds from the corresponding live weights shown in Table 32, the gains of the body protein ($N \times 6.0$) were as shown in Table 30.

TABLE 30
Daily gains of Protein ($N \times 6.0$)

	High-protein		Low-protein	
	Calf No. 71	Calf No. 72	Calf No. 73	Calf No. 74
<i>Per head</i>				
First digestion trial	42.96 grms.	31.86 grms.	25.26 grms.	16.44 grms.
Second digestion trial	31.32 grms.	10.92 grms.	11.46 grms.	11.58 grms.
<i>Per 1000 pounds live weight</i>				
First digestion trial	0.376 lb.	0.321 lb.	0.216 lb.	0.134 lb.
Second digestion trial	0.246 lb.	0.098 lb.	0.091 lb.	0.087 lb.

¹"Feeds and Feeding" 15th Ed., p. 647.

In the first trial, the high-protein animals made a much greater gain of protein than did the low-protein ones. In the second trial, Nos. 72, 73 and 74 showed remarkably small gains, falling to about the same low level, while No. 71 showed a more normal increase. As compared with the estimated "normal" gain of protein, computed in the manner described on p. 226, and with the amounts of digestible protein available for growth the results were as stated in Table 31.

TABLE 31

Protein supply and daily gains per 1000 pounds live-weight

	High-protein		Low-protein	
	No. 71 Age 301 days	No. 72 Age 301 days	No. 73 Age 331 days	No. 74 Age 331 days
	Lbs.	Lbs.	Lbs.	Lbs.
<i>First digestion trial</i>				
Digestible protein consumed	1.67	1.75	0.80	0.78
Estimated maintenance requirement	0.50	0.50	0.50	0.50
	1.17	1.25	0.30	0.28
Available for growth	0.38	0.32	0.22	0.13
Observed gain of protein	0.42	0.42	0.39	0.39
	Age 414 days	Age 414 days	Age 444 days	Age 444 days
	Lbs.	Lbs.	Lbs.	Lbs.
<i>Second digestion trial</i>				
Digestible protein consumed	1.73	1.65	0.66	0.62
Estimated maintenance requirement	0.50	0.50	0.50	0.50
	1.23	1.15	0.16	0.12
Available for growth	0.25	0.10	0.09	0.09
Observed gain of protein	0.31	0.31	0.29	0.29
Estimated normal gain				

Of the high-protein animals receiving protein largely in excess of the estimated minimum requirements and net energy not greatly below the estimated requirements, No. 71 closely approached the estimated "normal" gain while No. 72 fell about 25% below it in the first trial and about 66% below it in the second trial. This animal was described by the authors as "unthrifty." On the other

hand, both of the low-protein animals, on rations approaching the estimated requirements as regards energy, but with a protein supply distinctly below the estimated minimum, showed a rate of gain notably below the "normal."

LIVE WEIGHTS AND GAINS

The average live weights for 10 days at several intervals as compared with Eckles' results for the same ages, and the mean daily gains, are shown in Table 32.

TABLE 32

Weights and gains per head compared with normal

	High-protein			Low-protein		
	No. 71	No. 72	Eckles' average	No. 73	No. 74	Eckles' average
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
<i>Live weights</i>						
At beginning of experiment	214.5	190.3	435	230.1	240.6	475
At first digestion period	252.0	219.2	500	257.9	269.7	530
At second digestion period	281.4	246.9	592	278.5	294.4	609
Total gain as per cent of initial weight	31.2%	29.7%		21.0%	22.4%	
<i>Mean daily gains</i>	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
From beginning to first digestion trial; 52 days	0.72	0.56	1.25	0.53	0.56	1.06
From first to second digestion trial; 113 days	0.26	0.25	0.81	0.18	0.22	0.70
From beginning to second digestion trial; 165 days	0.41	0.35	0.95	0.30	0.33	0.81

In proportion to their live weight (Table 33) the animals showed in the first period a tendency to more rapid gain in weight than the computed normal, *i. e.*, they tended to make up lost time. In the second period, however, they fell much below the normal rate of increase, this difference being much larger on the low protein rations.

On the whole, both the live weight results and the nitrogen balances show a distinct advantage on the side of the high-protein

TABLE 33

Daily gain per 1000 average live weight at middle of period

	High-protein			Low-protein		
	Calf No. 71	Calf No. 72	Eckles' average	Calf No. 73	Calf No. 74	Eckles' average
From beginning to first digestion period (52 days)	3.09	2.72	2.67	2.19	2.20	2.11
From first to second digestion period (113 days)	0.98	1.06	1.48	0.69	0.78	1.23

rations but indicate that even these animals failed to gain weight or store protein at the normal rate for their age and size. Before ascribing these differences to the difference in the protein supply, however, it is necessary to consider whether the rations furnished sufficient energy.

In the first period, it appears from Table 29 that the net energy in both the high-protein and the low-protein rations was distinctly less than the estimated requirement yet the high-protein animals appear to have made almost a normal gain of protein (Table 31) and a super-normal gain of live weight for their size (Table 33). The low-protein animals, on the contrary, which received slightly less protein than the estimated minimum requirement, showed a distinctly sub-normal gain of protein but a nearly normal relative gain of live weight.

In the second and longer period, the energy supply of all the animals was nearly equal to the estimated requirement. In this period No. 71 of the high-protein animals made almost a normal gain of protein, while No. 72 (the "unthrifty" animal) showed a very low gain, but both animals made about $\frac{2}{3}$ the estimated normal increase in live weight. The low protein animals, whose protein supply was about $\frac{2}{3}$ of the estimated minimum requirement, showed a notably small increase in both body protein and in live weight.

It would appear, then, despite some irregularities and uncertainties, that the protein content of the low-protein rations, which was considerably lower than was intended, was a limiting factor in the growth of these animals.

INVESTIGATIONS AT THE VIRGINIA EXPERIMENT STATION
(CONTINUED)

EXPERIMENTS OF 1919

ANIMALS

For this experiment four pure-bred Holstein bull calves were selected, all of them relatively large animals. No's 2 and 3 seemed less thrifty than the other two and were therefore placed in different groups. The ages and weights at the beginning of the experiment, on June 1st, 1919, were as shown in Table 34. No grouping of the animals by pairs is reported. The live weights are notably greater than those reported by Eckles for light-fed Holstein calves of corresponding ages.

TABLE 34

Description of animals

		Date of birth	Age, June 1, 1919 days	Weight June 1, 1919 lbs.
High-protein	No. 1	December 16, 1918	166	440
	No. 2	November 29, 1918	183	395
Low-protein	No. 3	December 19, 1918	163	475
	No. 4	December 13, 1918	169	447

PERIODS AND RATIONS

The rations as computed were intended to correspond to those given in the plan. As was the case with the experiments of the previous year, the digestion trials showed that they were actually somewhat lower in net energy and decidedly lower in digestible protein than was intended.

The first rations computed, the feeding of which was begun on June 1st, proved to be too bulky for the animals to consume completely. Accordingly a portion of the oat straw was withdrawn from the ration and starch substituted for it. The feeding of this new ration began on June 29 and extended to August 1. On that date the rations were increased in amount to correspond with the increase in weight of the animals but the amounts of protein and energy per 1000

pounds live weight were intended to be the same as for the rations of the first period. The second period extended from August 1st to September 21st inclusive. The respective rations for the two periods are shown in Tables 35 and 36.

TABLE 35

Daily rations of first period

	High-protein		Low-protein	
	Calf 1	Calf 2	Calf 3	Calf 4
Age, June 29, 1919	194 days	211 days	191 days	197 days
Live weight for the 8 days ending June 28, 1919	480 lbs.	414 lbs.	487 lbs.	470 lbs.
<i>Rations Per Head</i>				
	Grams	Grams	Grams	Grams
Oat straw	1270	1134	1878	1814
Alfalfa hay	1724	1452	1161	1134
Maize meal	943	822	645	631
Linseed meal	425	376	291	284
Peanut meal	503	439	347	340
Starch	610	532	957	929

TABLE 36

Daily rations of second period

	High-protein		Low-protein	
	Calf 1	Calf 2	Calf 3	Calf 4
Age August 1st	227 days	244 days	224 days	230 days
Live weight for the 8 days ending July 31	527 lbs.	453 lbs.	516 lbs.	508 lbs.
<i>Rations Per Head</i>				
	Grams	Grams	Grams	Grams
Oat straw	1451	1225	2041	1996
Alfalfa hay	1905	1633	1270	1225
Maize meal	1056	907	695	680
Linseed meal	475	411	319	312
Peanut meal	567	489	376	369
Starch	680	588	1524	1496

The computations of the rations were based upon analyses of the feeding stuffs used, allowance being made in the second period for changes in the moisture content of the feeds.

DIGESTION AND METABOLISM EXPERIMENTS

As already stated, the digestibility of the total ration and the nitrogen balance were determined for each animal during each of the two periods, the excreta being collected quantitatively for the seven days July 15 to 21 and September 15 to 21 respectively.

Digestibility.—Table 37 shows the actual weights of the several nutrients digested per day and head together with the digestion coefficients:

TABLE 37
Amount digested per day and head

	High-protein				Low-protein			
	Calf No. 1		Calf No. 2		Calf No. 3		Calf No. 4	
	1st trial	2d trial	1st trial	2d trial	1st trial	2d trial	1st trial	2d trial
<i>Weights digested</i>								
<i>Grams</i>								
Dry matter	3156.2	3795.6	2826.6	3205.8	2757.1	3806.9	2984.8	3723.8
Organic matter	3080.7	3680.2	2740.4	3124.0	2697.7	3705.8	2924.8	3661.3
Crude protein	441.2	507.0	400.2	450.4	233.5	284.9	239.6	261.0
True protein	383.9	443.7	350.8	396.0	189.4	237.2	201.0	214.6
Crude fiber	550.8	667.0	494.8	535.5	474.6	601.6	507.3	659.9
Nitrogen-free extract	1969.6	2372.0	1742.3	2022.9	1907.4	2725.6	2082.3	2646.9
Ether extract	119.1	134.2	103.9	115.2	82.2	93.7	95.6	93.7
<i>Per cent digested</i>								
Dry matter	65.0	70.1	67.1	69.1	58.9	68.8	65.5	68.9
Organic matter	66.9	71.6	68.5	71.0	60.5	70.1	67.5	70.9
Crude protein	60.3	62.7	63.2	64.8	43.8	49.4	46.1	46.5
True protein	56.7	59.6	60.1	61.8	38.7	44.9	41.7	41.6
Crude fiber	51.3	55.5	53.0	52.4	42.3	49.4	46.6	55.6
Nitrogen-free extract	73.8	79.8	75.0	79.4	70.7	80.9	77.5	80.3
Ether extract	82.0	83.2	82.2	83.2	72.5	76.7	86.5	78.6

As in the experiments of the previous year, the results show a distinct depression of digestibility in the low-protein rations, particularly as regards the digestibility of the protein and the crude fiber. This resulted in lowering the protein supply of the low-protein group considerably below the amount intended to be fed. In distinction from the results of the previous year, the digestibility of the crude fiber also shows a distinct depression, except in one instance, while the figures for the nitrogen-free extract show but slight differences. The digestibility in the second trial is distinctly higher than in the first, while in 1918 little difference was noted.

As in all the other experiments of the series, the actual digestibility of the mixed rations, as to both dry matter and protein, differed from that computed by the use of average digestion coefficients, as appears from the comparisons in Table 38.

TABLE 38
Observed and computed digestibility of dry matter and crude protein

	Dry matter		Crude protein	
	Observed	Computed	Observed	Computed
<i>First period</i>				
High-protein				
No. 1	65.0	71.3	60.3	78.1
No. 2	67.1	71.4	63.2	78.2
Low-protein				
No. 3	58.9	71.0	43.8	75.2
No. 4	65.5	71.0	46.1	75.3
<i>Second period</i>				
High-protein				
No. 1	70.1	71.3	62.7	78.0
No. 2	69.1	71.4	64.8	78.1
Low-protein				
No. 3	68.8	73.3	49.4	75.1
No. 4	68.9	73.4	46.5	75.1

The high-protein rations show only small differences in the digestibility of the dry matter (1.2 to 6.3) but much more marked ones in that of the crude protein (13.3 to 17.8). In the low-protein

rations the discrepancy is somewhat greater in the dry matter (4.5 to 12.1) and strikingly large in the crude protein (25.7 to 31.4). The supply of digestible protein and of net energy was therefore much less than was intended, particularly in the low-protein rations.

Intended and actual feed supply.—The digestible true protein and the net energy of the rations consumed in the digestion trials has been computed in the same way as in the experiments of the previous year, the energy being computed in the two different ways. The results computed per 1000 pounds live weight at the time of the digestion trials were as follows:

TABLE 39

Protein and energy supply per 1000 lbs. live weight in digestion trials

	First trial		Second trial	
	Digestible true protein	Net energy	Digestible true protein	Net energy
	Lbs.	Therms	Lbs.	Therms
<i>High-protein</i>				
Calf No. 1				
Intended	2.40	14.50	2.40	14.50
Observed	1.71	$\begin{cases} 13.75^1 \\ 11.73^2 \end{cases}$	1.60	$\begin{cases} 12.41^1 \\ 12.06^2 \end{cases}$
Calf No. 2				
Intended	2.40	14.50	2.40	14.50
Observed	1.82	$\begin{cases} 13.96^1 \\ 12.43^2 \end{cases}$	1.70	$\begin{cases} 12.70^2 \\ 12.10 \end{cases}$
<i>Low-protein</i>				
Calf No. 3				
Intended	1.62	14.50	1.62	14.50
Observed	0.85	$\begin{cases} 12.63^1 \\ 9.33^2 \end{cases}$	0.91	$\begin{cases} 13.17^1 \\ 12.82^2 \end{cases}$
Calf No. 4				
Intended	1.62	14.50	1.62	14.50
Observed	0.90	$\begin{cases} 12.36^1 \\ 11.40^2 \end{cases}$	0.82	$\begin{cases} 12.73^1 \\ 12.66^2 \end{cases}$

¹As computed by the authors.

²As computed by the writer.

Gains of protein.—Computed from the nitrogen balances of the two metabolism trials and from the corresponding live weights at those dates, as shown in Tables 35 and 36, the daily gains of body protein ($N \times 6.0$) per head and per 1000 pounds live weight were as shown in Table 40.

TABLE 40

Daily gains of protein ($N \times 6.0$)

	High-protein		Low-protein	
	Calf No. 1	Calf No. 2	Calf No. 3	Calf No. 4
<i>Per head</i>				
First digestion trial	146.82 grms.	90.54 grms.	43.56 grms.	65.34 grms.
Second digestion trial	122.70 grms.	64.14 grms.	83.70 grms.	58.20 grms.
<i>Per 1000 pounds live weight</i>				
First digestion trial	0.65 lb.	0.47 lb.	0.20 lb.	0.29 lb.
Second digestion trial	0.44 lb.	0.28 lb.	0.32 lb.	0.22 lb.

The results as compared with the estimated normal gain of protein, computed as in previous cases, and with the amounts of digestible protein available for growth, are shown in Table 41.

In the first trial, the gains of protein were notably greater by the high-protein animals, closely approaching or even exceeding the estimated normal, while the low-protein animals reached only one-half to one-third the normal on rations supplying somewhat less than the estimated minimum requirement for normal growth. In the second trial, one of the high-protein animals (No. 1) continued to show a normal gain but the other (No. 2) dropped to the level of the low-protein animals, all three being much below the normal. In other words, the protein supply seems to have been the limiting factor in the growth of the low-protein animals.

LIVE WEIGHTS AND GAINS

The rations fed were computed upon the initial live weights of each animal on the average of the eight days preceding the beginning of each period. These weights, together with those for the eight days preceding each digestion trial, and the corresponding gains as compared with Eckles' results for the same ages*, are recorded in Table 42.

*Mean age of the two animals.

TABLE 41

Protein supply and daily gains per 1000 pounds live weight

	High-protein		Low-protein	
	No. 1 Age 210 days	No. 2 Age 227 days	No. 3 Age 207 days	No. 4 Age 213 days
<i>First digestion trial</i>	Lbs.	Lbs.	Lbs.	Lbs.
Digestible protein consumed	1.71	1.82	0.85	0.90
Estimated maintenance requirement	0.50	0.50	0.50	0.50
Available for growth	1.21	1.32	0.35	0.40
Observed gain of protein	0.65	0.47	0.20	0.29
Estimated normal gain	0.59	0.55	0.60	0.58
	Age 272 days	Age 289 days	Age 269 days	Age 275 days
<i>Second digestion trial</i>	Lbs.	Lbs.	Lbs.	Lbs.
Digestible protein consumed	1.60	1.70	0.91	0.82
Estimated maintenance requirement	0.50	0.50	0.50	0.50
Available for growth	1.10	1.20	0.41	0.32
Observed gain of protein	0.44	0.28	0.32	0.22
Estimated normal gain	0.46	0.44	0.47	0.46

The gains in live weight per 1000 pounds, as shown in Table 43, are computed upon the basis of the live weight at the middle of each period. For example, in case of Calf No. 1, in the first period the weight is taken to be the average of 480 pounds and 496 pounds and that for the second period the average of 496 pounds and 527 pounds. Table 43 shows the live weights and gains computed in this manner as compared with Eckles' results for the same age.

Not only were the animals, as already noted, heavy for their age at the start of the experiments but their gains were both absolutely and relatively greater than those reported by Eckles for animals of the same breed. It would seem that they had an

TABLE 42

Live weights and gains per head compared with normal

	High-protein			Low-protein		
	No. 1	No. 2	Eckles' average	No. 3	No. 4	Eckles' average
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
<i>Live weights</i>						
At beginning of experiment	480	414	381	487	470	369
At first digestion trial	496	426	400	493	490	389
At beginning of 2d period	527	453	421	516	508	411
At second digestion trial	612	514	480	573	580	468
Total gain as per cent of initial weight	27.5%	24.2%		17.7%	23.4%	
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
<i>Daily gains</i>						
From beginning to first di- gestion trial; 16 days	1.00	0.75	1.19	0.38	1.25	1.25
From first digestion trial to beginning of 2d pe- riod; 17 days	1.82	1.59	1.24	1.35	1.06	1.29
From beginning of 2d pe- riod to second digestion trial; 45 days	1.89	1.36	1.31	1.26	1.59	1.27
For entire experiment; 78 days	1.69	1.29	1.27	1.10	1.41	1.27

unusual capacity for growth. The rapid increase can hardly be attributed to fattening since the computations of Table 39 show the amounts of net energy consumed to have been materially lower than the estimated requirements for normal growth with no considerable fattening and but slightly greater on the whole for the high-protein than for the low-protein animals.

On the whole the live weight results seem to confirm the conclusion drawn from the nitrogen balances that the unintended reduction of the protein supply of Nos. 3 and 4 below the estimated minimum requirement resulted in a rate of growth less than the normal.

TABLE 43

Daily gain of weight per 1000 lbs. average live weight at middle of period

	High-protein			Low-protein		
	Calf No. 1	Calf No. 2	Normal	Calf No. 3	Calf No. 4	Normal
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
From beginning to first digestion trial	2.05	1.79	3.04	0.78	2.60	3.30
From first digestion trial to beginning of 2d period	3.55	3.61	3.02	2.65	2.12	3.12
From beginning of 2d period to second digestion trial	3.32	2.81	2.90	2.31	2.92	2.89
For entire experiment	3.10	2.78	2.95	2.08	2.69	3.03

DISCUSSION OF RESULTS

Method of expression.—It has been a quite common practice to express the results of investigations on the protein requirements of animals in terms of a ratio or percentage. In experiments on animal nutrition the so-called nutritive ratio, originally devised as an aid to the practical feeder in the computation of rations, has found wide application. In more strictly biological investigations, much use has been made of a similar relation, viz., the percentage of the total energy of the feed which is contained in its protein. For example, an animal receiving feed containing 16 per cent of its energy in the form of protein has been regarded as being on a higher protein level than one whose feed contained only 12 per cent of its energy in the form of protein. For many purposes this is a convenient method of expression but it is liable to be misleading unless its limitations are recognized.

Growth is not supported by ratios or percentages but by protein and energy. If a feed with a low percentage of its energy in the form of protein gives inferior results, as measured by live weight, it is not because of this low percentage in itself but because the amount of the feed consumed fails to supply either enough grams of protein or enough calories of total energy, or both. Failure to realize this vitiates the conclusions drawn from numerous

experiments. The error is of the same nature as that which, as Osborne and Mendel¹ have recently pointed out, likewise vitiates many investigations regarding vitamins. It is only when the energy supply of the animals to be compared is the same, as the same authors² have insisted, that a comparison of percentages of protein calories is significant. For this reason stress was laid in the plan for these experiments upon equality of energy supply, although the efforts in that direction did not prove particularly successful so far as can be judged from the evidence of the balance experiments. The writer believes that in discussing experiments of this sort confusion of thought may often be avoided by dealing with quantities of protein and energy rather than with proportions, particularly in the comparison of the actual results with the normal rate of growth.

THE RESULTS OF THE METABOLISM TRIALS

The object of the metabolism trials was, first to determine the actual feed supply with greater accuracy than could be hoped for by the use of average digestion coefficients and second, to determine the gain of protein (nitrogen balance) of the animals as a measure of the true growth rather than to depend entirely on the live weights. The determinations of the nitrogen balance seemed also to offer a further probable advantage of being less dependent upon equality in the energy supply than are comparisons based on the live weight, provided of course, that there was not a deficiency of energy. If the lower energy supply was sufficient to protect the protein from being katabolized, an additional amount of energy might be expected to result in an increase of live weight due to fattening without any material influence upon the gain of protein.

As appears from the foregoing records of the experiments, however, these presumable advantages proved more or less illusory for various reasons.

The digestibility of the rations.—The results of the digestion trials seem to show very clearly that the actual feed supply of experimental animals may differ materially from that computed by the use of average digestion coefficients both as regards the total feed (energy) and especially as regards protein. This is

¹Jour. Biol. Chem., 45 (1921), 283.

²Jour Biol. Chem., 26 (1916), 1.

most obvious in the case of the low-protein rations, where the familiar depression of digestibility caused by a large proportion of carbohydrates was very manifest, but it was true also of the high-protein rations. Table 44 summarizes the amounts of digested true protein and of net energy (computed in the manner described in connection with the several experiments) actually consumed according to the testimony of the digestion trials compared with that computed and intended to have been consumed.

The results shown in Table 44 are more or less fluctuating but on the average of all the trials the digestibility of both the protein and energy of the high-protein rations was about 80 per cent of that computed from the actual composition of the feeding stuffs by the use of average digestion coefficients. Ewing and his associates¹ have observed similar discrepancies between the observed and computed digestibility of the mixed rations of cattle and Rubner² reports similar observations on a dog, with which, however, mixtures of vegetable foods showed a higher digestibility than was computed. On the other hand Hummel³ in experiments on cows, using, however, only four-day collection periods, observed no significant differences. In the case of the low-protein rations in these experiments the reduction of the energy supply below that computed was little more than in the high-protein rations, viz., 24 per cent as compared with 20 per cent. The digestibility of the protein, on the contrary, fell much lower than in the high-protein rations, averaging only 68 per cent of that computed. This phenomenon also is a familiar one. The general teaching of the experiments is substantially the same whether the somewhat questionable results of the Massachusetts experiments of 1919 are included or excluded.

The gains of protein.—In presenting on previous pages the results obtained at the several stations the attempt has been made to compare the gain of protein as shown by the nitrogen balances with the amount of protein available to sustain growth after the maintenance requirement was satisfied. In the absence of any more satisfactory data, the maintenance requirement of protein has been assumed to have been uniformly 0.50 per thousand

¹Journal of Agr'l Research, 13 (1918), 611.

²Arch. (Anat u.) Physiol., 1918, 135.

³Minnesota Expt. Sta., Bul. 99 (1907), 121-132.

TABLE 44
Protein and energy supply per 1,000 pounds live weight compared with that computed

	High-protein rations						Low-protein rations					
	Protein			Energy			Protein			Energy		
	Com- puted	Actual	Actual ÷ com- puted	Com- puted	Actual	Actual ÷ com- puted	Com- puted	Act ua l	Actual ÷ com- puted	Com- puted	Actual	Actual ÷ com- puted
	Lbs.	Lbs.	Per cent	Therms	Therms	Per cent	Lbs.	Lbs.	Per cent	Therms	Therms	Per cent
Massachusetts Station, 1918												
Pair III	2.00	1.74	87	11.80	8.84	75	1.00	0.84	84	11.80	7.26	62
Pair IV, first trial	2.03	1.80	89	12.10	8.53	70	1.07	0.98	92	12.10	8.62	71
Pair IV, second trial	2.00	1.73	87	11.80	8.72	74	1.00	0.70	70	11.80	7.52	64
Means	2.01	1.76	88	11.90	8.70	73	1.02	0.84	82	11.90	7.80	66
Massachusetts Station, 1919												
Pair II, Period II	2.55	2.23	87	15.30	13.44	88	1.69	1.40	83	15.30	12.12	79
Pair II, Period VI	(2.25)	(1.69)	(75)	(13.60)	(6.09)	(45)	(1.48)	(1.04)	(70)	(13.60)	(7.72)	(57)
Pair II, Period X	2.08	1.92	92	12.55	11.05	88	(1.32)	(1.06)	(80)	(12.55)	(8.16)	(65)
Pair III, Period IV	2.25	1.78	79	13.60	11.48	84	1.48	1.00	68	13.60	10.76	79
Pair III, Period VIII	2.08	1.85	89	12.55	10.37	83	1.32	1.07	81	12.55	8.51	68
Pair III, Period XII	2.01	1.24	62	11.95	6.66	56	1.18	0.77	65	11.95	8.07	68
Means												
Corrected means	2.20	1.79	81	13.26	9.85	74	1.41	1.06	75	13.26	9.52	72
	2.24	1.95	87	13.50	11.59	86	1.42	1.06	77	13.35	9.87	74

TABLE 44 (Continued)

	High-protein rations						Low-protein rations					
	Protein			Energy			Protein			Energy		
	Com- puted	Actual	Actual ÷ com- puted	Com- puted	Actual	Actual ÷ com- puted	Com- puted	Actual	Actual ÷ com- puted	Com- puted	Actual	Actual ÷ com- puted
	Lbs.	Lbs.	Per cent	Therms	Therms	Per cent	Lbs.	Lbs.	Per cent	Therms	Therms	Per cent
Virginia Station, 1918												
Nos. 71 and 74, first trial	2.20	1.67	76	13.30	11.24	85	1.20	0.78	65	12.71	10.45	82
Nos. 71 and 74, second trial	2.03	1.73	85	12.10	11.96	99	1.00	0.62	62	11.80	11.24	95
Nos. 72 and 73, first trial	2.20	1.75	80	13.30	10.50	79	1.20	0.80	67	12.71	10.08	79
Nos. 72 and 73, second trial	2.03	1.65	81	12.10	10.52	87	1.00	0.66	66	11.80	11.59	98
Means	2.12	1.70	80	12.70	11.06	87	1.10	0.71	65	12.26	10.84	88
Virginia Station, 1919												
Nos. 1 and 4, first trial	2.40	1.71	71	14.50	11.73	81	1.62	0.90	56	14.50	11.40	79
Nos. 1 and 4, second trial	2.40	1.60	67	14.50	12.06	83	1.62	0.82	51	14.50	12.66	87
Nos. 2 and 3, first trial	2.40	1.82	76	14.50	12.43	86	1.62	0.85	52	14.50	9.32	64
Nos. 2 and 3, second trial	2.40	1.70	71	14.50	12.10	83	1.62	0.91	56	14.50	12.82	88
Means	2.40	1.71	71	14.50	12.08	83	1.62	0.87	54	14.50	11.55	80
Means of all	2.18	1.74	80	13.09	10.42	80	1.29	0.87	68	12.98	9.93	76
Corrected means of all*	2.19	1.78	81	13.15	10.86	80	1.29	0.87	68	13.00	10.02	77

*Omitting doubtful results in 1919.

TABLE 45

Protein available for growth compared with normal and with observed gain of protein

	High-protein							Low-protein								
	Animal	Period	Age-days	Feed protein available		Normal gain per 1000	Observed gain per 1000	Per cent of available protein utilized	Animal	Period	Age-days	Feed protein available		Normal gain per 1000	Observed gain per 1000	Per cent of available protein utilized
				Total per 1000	Per cent of normal gain							Total per 1000	Per cent of normal gain			
Massachusetts, 1918	5	6	386	1.24	376	0.33	0.57	46	6	6	386	0.34	103	0.33	0.41	121
	7	5	372	1.30	382	0.34	0.35	27	8	5	372	0.48	141	0.34	0.29	60
	7	6	394	1.23	373	0.33	0.48	39	8	6	394	0.20	61	0.33	0.26	130
Total and means				3.77	377	1.00	1.40	37				1.02	102	1.00	0.96	94
Massachusetts, 1919	21	II	152	1.73	219	0.79	0.49	28	20	II	161	0.90	120	0.75	0.64	71
	21	VI	212	1.19	205	0.58	-0.43	59	20	VI	221	0.54	96	0.56	-0.60	38
	21	X	272	1.42	309	0.46	0.84	35	20	X	281	0.56	124	0.45	-0.05	37
	23	IV	239	1.28	246	0.52	0.45	45	22	IV	239	0.50	96	0.52	0.19	70
	23	VIII	301	1.35	321	0.42	0.61	45	22	VIII	301	0.57	136	0.42	0.21	55
Totals and means*	23	XII	361	0.74	211	0.35	-0.26	41	22	XII	361	0.27	77	0.35	0.19	—
				5.78	264	2.19	2.39	41				2.24	110	2.04	1.23	—

TABLE 45—(Continued)

	High-protein								Low-protein							
	Animal	Period	Age-days	Feed protein available			Normal gain per 1000	Observed gain per 1000	Per cent of available protein utilized	Animal	Period	Age-days	Total per gain	Per cent of normal 1000	Normal gain per 1000	Observed gain per 1000	Per cent of available protein utilized
Virginia, 1918	71	1	301	1.17	279	0.42	0.38	32	73	1	331	0.30	77	0.39	0.22	73
	71	2	414	1.23	397	0.31	0.25	20	73	2	444	0.16	55	0.29	0.09	56
	72	1	301	1.25	298	0.42	0.32	26	74	1	331	0.28	72	0.39	0.13	46
	72	2	414	1.15	371	0.31	0.10	9	74	2	444	0.12	41	0.29	0.09	75
Totals and means				4.80	329	1.46	1.05	22				0.86	67	1.36	0.53	62
Virginia, 1919	1	1	210	1.21	205	0.59	0.65	54	3	1	207	0.35	58	0.60	2.20	57
	1	2	272	1.10	239	0.46	0.44	40	3	2	269	0.41	87	0.47	0.32	78
	2	1	227	1.32	240	0.55	0.47	36	4	1	213	0.40	69	0.58	0.29	73
	2	2	289	1.20	273	0.44	0.28	23	4	2	275	0.32	70	0.46	0.22	69
Totals and means				4.83	237	2.04	1.84	38				1.48	70	2.11	1.03	70

*Omitting Period VI for both high and low protein, Period X for the low-protein and Period XII for the high-protein.

on the strength of results reported elsewhere by the writer.¹ It is fully recognized that this figure is uncertain and may be considerably in error in individual cases.

The results of these comparisons are summarized in Table 45, in which the protein available for growth after the estimated maintenance requirement is provided for is compared with the observed gain of protein and with the normal gain computed in the manner described on page 226.

Comparing first the results on the low-protein with those on the high-protein animals, it appears that except in a single instance out of fourteen (excluding the apparent negative gains in the Massachusetts experiments of 1919) the animals receiving the high-protein rations showed a greater gain of protein per 1000 than did their mates on the low-protein rations. Comparing the means for the several years, it appears that the gains of protein made by the low-protein groups were the following percentages of those made by the high-protein groups:

Massachusetts experiments of 1918	68.6%
Virginia experiments of 1918	50.5%
Massachusetts experiments of 1919	51.5%
Virginia experiments of 1919	56.0%

On the other hand, a comparison of the gains of protein by the low-protein animals with the estimated normal gain of protein presents a somewhat different picture. The individual results are strikingly variable but some indication of their general trend may perhaps be secured from the means for the several groups.

In the Massachusetts experiments, omitting, as in the discussion of digestibility, the doubtful periods in 1919, it appears that on the average of the remaining metabolism experiments the digested protein available for growth was but slightly greater than the estimated normal increase of body protein. On this amount in 1918 almost normal growth (96%) appears to have been made, which is equivalent to the utilization of 94% of the available protein. In 1919, on the contrary, the increase of body protein was much less than the assumed normal growth (60%, equivalent to 65% utilization). On the high-protein rations, on the other hand, the average increase of body protein was decidedly greater

¹"Nutrition of Farm Animals," page 327.

than the assumed normal and this was also true in four out of the seven individual cases. Since, however, these rations obviously supplied a surplus of protein, the percentage utilization is apparently low.

In the experiments at the Virginia Station, on the other hand, the estimated protein available for growth was on the average only about 70 per cent of the normal protein gain and the increase of body protein was only 39 per cent of the normal in 1918 and 49 per cent in 1919, or 45 per cent on the average of both years, while the energy supply of the low-protein animals was only slightly less (97%) than that of the high-protein group. It seems clear that the smaller gains were due, at least in greater part, to an actual deficiency of protein due to the reduced digestibility of the rations.

The following is a condensed comparison of the foregoing results:

	Available protein in per cent of "normal" gain	Gain of protein in per cent of "normal" gain
Massachusetts experiments of 1918	102%	96%
Massachusetts experiments of 1919	110%	60%
Virginia experiments of 1918	67%	39%
Virginia experiments of 1919	70%	49%

A curious fact is that the deficient protein supply in the Virginia experiments seems to have so affected the power of growth that the percentage utilization of the protein available for growth was only 60 to 70 per cent whereas one would have expected that this diminished supply would have been used with the utmost economy.

It remains to be considered whether the inferior results on the low-protein as compared with the high-protein rations were due to lack of sufficient protein or to a deficient energy supply. It is difficult to answer this question very satisfactorily. In the Massachusetts experiments the average energy supply of the low-protein animals in 1918 was 90 per cent of that of the high-protein animals (Table 44), yet the low-protein animals made an almost normal gain. In 1919 the energy supply of the low-protein group was 85 per cent of that of the high-protein. The difference

between the two years seems scarcely sufficient to account for the notably inferior results in 1919. These low results are substantially all on one animal, No. 22. In view of the fact that this animal made about the same gains of live weight as did the others (page 251), and in view of the seemingly erratic results of the nitrogen balances of 1919 the writer is inclined to interpret the Massachusetts results as indicating that a protein supply but slightly in excess of the total maintenance plus gain sufficed to secure nearly normal growth although insufficient to ensure maximum growth, *i. e.*, that the particular protein mixture used was nearly 100 per cent efficient. In view of the small number of results, however, this opinion is held only tentatively.

In the Virginia experiments the energy supply of the low-protein animals was 93 per cent of that of the high-protein animals in 1918 and 97 per cent in 1919. It would seem, therefore, that the smaller gains of protein by the former as compared with the latter or with the estimated normal must have been due chiefly to lack of protein.

Are the metabolism experiments representative?—A metabolism trial necessarily involves more or less disturbance of the regular daily routine and if the animal is not accustomed to such experimentation it may interfere with securing normal results. This would seem to have been the case especially in the Massachusetts experiments of 1919, as is noted in the account of those trials, while the figures of the remaining experiments do not suggest any such influence. In all such experimentation, however, the preliminary training of the animals is a matter of much importance. In the experience of the writer, mature cattle, especially if selected with reference to their quietness, may be quite readily trained for such experiments and at least show no obvious effects of it upon their metabolism. In the case of young animals the proper selection and the subsequent training may very well offer greater difficulty and cause greater disturbance in their condition. This is a point which must be taken into consideration in the planning of experiments of this sort.

Aside from the foregoing considerations, a metabolism trial can cover only a small fraction of an entire feeding period and the question may be raised as to how far one is justified in assuming that a metabolism trial conducted under proper conditions represents such a period.

As regards digestibility it may be regarded as pretty well established that, with similar rations not differing widely in amount, the age of the experimental animals is not an important factor, that the variations in the digestibility of the rations from time to time are not very great,¹ and that the differences observed may have sometimes arisen from too short periods for the collection of the feces. While there is a certain possibility of error, the writer believes it to be much less in carefully conducted experiments than the relatively large ones which may apparently be involved in the use of average digestion coefficients.

As regards the urinary nitrogen, we have little basis for comparison. We must either forego any determination of the actual gain or loss of protein by the animal or depend on making as frequent balance trials as practicable, conducting them with as little disturbance to the animal as possible.

Furthermore, it may be remarked that, barring a disturbance of the animal's metabolism by the experimental conditions, a metabolism trial shows the digestibility and rate of gain of protein at a particular date—a sort of instantaneous photograph of what is going on in the body—and the results may be compared with what we regard as normal for that species and age. If even two or three points on the curve of growth can thus be definitely fixed a comparison with the results of reasonably frequent weighings and measurements should give a pretty definite idea as to the efficiency of the rations. The writer is at present inclined to think that more frequent metabolism trials, if they can be conducted without undue disturbance of the experimental animals, is a hopeful line of approach to problems of this nature. For mature cattle on rather light rations he has found no difficulty in securing apparently normal results from continuous metabolism trials covering as much as 100 days. It may well be doubted, however, whether normal growth could be obtained under such conditions but more study of the technique of this sort of investigation seems very desirable.

Was the protein mixture identical?—The plan of the experiments contemplated the use of an identical mixture of proteins in all cases, the computation of the proportions of the four feeding stuffs necessary to secure this being based on their actual composition and on average digestibility. The actual digestibility of

¹Compare "Nutrition of Farm Animals," page 602-3.

the total protein of the rations, however, was decidedly less than that computed and there is no means of determining whether or not this deficit of digestibility affected all the individual proteins proportionally. We can only assume that the differences, if any, were not sufficient to seriously vitiate the comparisons of the rations.

LIVE WEIGHTS AND MEASUREMENTS

The results of the weighings and measurements of the animals have been considered in the accounts of the individual experiments. Reference to these will show that in general the live weights confirm the conclusions drawn from the results of the metabolism experiments although on the whole making a rather more favorable showing for the low-protein rations as compared with the high-protein.

In comparing the gains in live weight it would appear that account should be taken of the differences in the initial weights of the animals, since obviously a gain of 50 pounds, *e. g.*, by an animal originally weighing 200 pounds is relatively greater than the same gain by one originally weighing 250 pounds. In other words, the smaller animal would double its weight more quickly. It would seem, therefore, that a fairer expression of the results would be obtained by expressing the gains as percentages of the initial weights of the animals. Table 46 summarizes both the actual and the percentage gains by all the animals, grouped in pairs as arranged by the experimenters. It appears from these results that the increase in live weight, both absolute and relative, by the low-protein animals was in every case except the Ohio experiments somewhat less than that made by the high-protein animals. Comparing the means of the several experiments, the increase by the low-protein animals was the following percentage of that made by the high-protein animals.

	On basis of absolute gains	On basis of relative gains
Massachusetts experiments of 1918	88%	88%
Virginia experiments of 1918	83%	71%
Ohio experiments of 1918	100%	105%
Massachusetts experiments of 1919	99%	93%
Virginia experiments of 1919	84%	79%

TABLE 46
Gains in live weight

	High-protein					Low-protein				
	Animal	Total gain	Percentage gain	Normal total gain	Normal percentage gain	Animal	Total gain	Percentage gain	Normal total gain	Normal percentage gain
Massachusetts, 1918	No.	Lbs.	Per cent	Lbs.	Per cent	No.	Lbs.	Per cent	Lbs.	Per cent
	269	176.0	75.2	170	51.4	270	136.0	67.3	173	68.1
	3	194.5	71.0	218	66.9	4	174.0	60.8	209	59.9
	5	181.5	69.8	209	59.9	6	161.5	61.2	209	59.9
	7	187.0	74.5	209	59.9	8	176.0	65.9	209	59.9
	Means	184.8	72.5	201.5	61.5	Means	161.9	63.5	200.0	61.5
Massachusetts, 1919	19	171.0	79.9	252	101.2	18	217.5	71.9	227	75.2
	21	228.5	80.5	252	101.2	20	226.5	78.5	239	86.6
	23	212.5	70.8	209	59.9	22	207.5	69.7	209	59.9
	25	221.0	67.7	178	43.7	24	170.0	56.7	178	43.7
	Means	208.3	74.1	222.8	71.1	Means	205.4	69.1	213.3	63.9
Ohio, 1918		141	41.0	124	39.2		141	43.0	124	39.2
Virginia, 1918	71	66.9	31.2	160	37.6	73	48.4	21.0	138	29.6
	72	56.6	29.7	160	37.6	74	53.8	22.4	138	29.6
	Means	61.8	30.5	160	37.6	Means	51.1	21.7	138	29.6
Virginia, 1919	1	132	27.5	97	26.3	3	86	17.7	97	26.3
	2	100	24.2	95	24.4	4	110	23.4	97	26.3
	Means	116	26.0	96	25.3	Means	98	20.5	97	26.3

Compared in either of these ways, the results are in favor of the high-protein rations, although not so markedly as those on the protein gains considered on pages 276-283.

The gains in live weight may also be compared with the normal gains for age as estimated from Eckles' results. This has been done in columns 4, 5, 9 and 10 of Table 46. It appears that the absolute gains in pounds by the high-protein animals were greater than the estimated normal for that age in six cases out of thirteen while with the low-protein animals the increases in weight were less than the estimated normal in every case but one.

If, however, account be taken of the differences in initial weight, and the comparison be made between the percentage gains it appears that the *relative* increase in weight by the high-protein animals was greater than the estimated normal in eight cases out of thirteen and that the same thing is true of the low-protein animals in six cases out of thirteen.

The question of special interest, of course, is whether the low-protein rations were adequate to support normal growth. A comparison of the means of Table 46 shows the increase by the low-protein animals to have been the following percentages of the estimated normal.

	On basis of absolute gains in pounds	On basis of gains per 100 initial weight
Massachusetts experiments of 1918	81%	103%
Virginia experiments of 1918	37%	48%
Ohio experiments 1918	114%	110%
Massachusetts experiments of 1919	96%	108%
Virginia experiments of 1919	101%	78%

In general it appears that the relative gain in weight by the low-protein animals was fully equal to the normal in the Massachusetts and Ohio experiments but distinctly below it in the Virginia experiments. This fact as regards the Massachusetts and Virginia experiments seems to correspond with the available protein supply in excess of maintenance as shown in Table 45 and already considered on pages 281-285.

On the whole, the live weight results make a distinctly more favorable showing for the low-protein rations than do the results of the metabolism experiments, although the advantage still appears to be slightly in favor of the high-protein rations, a fact which is perhaps explicable by their slightly greater energy content. The measurements of the animals in the Massachusetts experiments appear in general to confirm the live weight results.

Heat Values and Food Values.



BY HENRY PRENTISS ARMSBY, PH.D., LL.D.,
Agricultural Experiment Station,
State College, Pennsylvania.

Reprinted from THE ARCHIVES OF PEDIATRICS, February, 1905.

E. B. TREAT & CO., PUBLISHERS,
241-243 West 23d Street, New York.

HEAT VALUES AND FOOD VALUES.

BY HENRY PRENTISS ARMSBY, PH.D., LL.D.

Agricultural Experiment Station, State College, Pennsylvania.

Perhaps the most characteristic feature of the more recent studies in nutrition is the extent to which its various problems have come to be regarded as problems in energetics. While it is no less true than of yore that the nutrients of the food serve to make good the losses of body substance consequent upon the vital activities and to build up new tissue, we have come to see that these are, after all, in a sense, subsidiary processes—that the animal body is essentially a transformer of energy and that the main function of food is to supply this energy.

This new point of view has been of immense advantage, particularly in introducing greater unity and simplicity into thought and discussion, but it has also given rise to some unfortunate misconceptions. The most convenient measure of the potential energy of the food is afforded by the amount of heat evolved when the food is completely oxidized; *i. e.*, by its heat of combustion. Moreover, the larger share of the energy liberated in the body leaves it in the form of heat, while the maintenance of an approximately constant body temperature is, in the higher animals, essential to the health and even the life of the organism. Very naturally, therefore, the quantities of energy involved in nutrition have been measured and expressed by means of some accepted heat unit; ordinarily the calorie. There is no objection to this, provided it is clearly understood that this unit is employed simply as a matter of practical convenience. Unfortunately, however, this has not always been the case, and the statement of food energy, body energy, etc., in terms of heat units has given rise to a tendency to identify heat and energy and to regard heat production as the principal function of the food. A more careful study of the subject, however, shows that, so far from this being the case, the heat production by the animal is, in an important sense, incidental, and the heat, to a considerable degree, an excrementum.

In considering the thermal relations between the animal and its environment, it conduces to simplicity to consider first the case of a fasting animal in a state of external rest. Numerous observations have shown that under these conditions the metabolic activ-

ARMSBY: *Heat Values and Food Values.*

ities speedily tend to be reduced to the minimum required for the performance of the necessary bodily functions. Without attempting nice distinctions, we may say that such an animal expends energy for three general purposes. First, for the muscular work of the internal organs (especially of circulation and respiration), the maintenance of muscular tonus and such incidental muscular exertions as are made in what is commonly regarded as a state of rest; second, for the activities of the various secretory, absorptive and excretory organs, which we may roughly designate as glandular work; third, for such processes as imbibition, osmosis karyokinesis and the like, which we may call for convenience, cellular work. All these various forms of "internal work" are performed at the expense of the chemical energy stored up in the constituents of the tissues. This energy takes varied forms in different tissues and during different processes, but since the animal at rest does no mechanical work on its surroundings, it all ultimately appears as heat. It is important to note, however, that it is not until the original chemical energy has served its physiological purposes that it takes the form of heat. It is not first converted into heat which is then further converted into muscular or other work, but on the contrary it first gives rise to the muscular or other energy required, and the latter, in performing its functions, is degraded into heat. In other words, we have no evidence that the animal body is a form of heat engine. It is evident, then, that at least a part of the heat production of the animal is incidental to other purposes. At the same time, of course, the heat thus produced is available to maintain the body temperature, and the question at once arises whether the supply thus incidentally provided is sufficient, or whether additional body tissue must be metabolized simply for the sake of producing heat.

A satisfactory answer to this question requires a brief consideration of the manner in which heat escapes from the body.

Since the necessary metabolism of the living animal is a continual source of heat, it is obvious that in order to maintain the approximately constant body temperature of the warm-blooded animal the body must be able to give off this heat at the same average rate at which it is produced. Thus it has been computed that the heat produced in the human body in a single day, if all retained, would raise it to a pasteurizing temperature.

The body eliminates its heat in three principal ways, *viz.*, by conduction, by radiation and by vaporization of water. At moder-

ate temperatures, the two processes first named are chiefly active. With a rise in the external temperature the tendency is, of course, to check the outflow of heat by these channels. This is counteracted, however, by a relaxation of the peripheral blood vessels, allowing a more rapid flow of blood through the capillaries and thus facilitating the elimination of heat. If the temperature continues to rise, this mechanism of regulation becomes inadequate, and the third process, the vaporization of water, comes into play in the familiar phenomenon of sweating, large amounts of heat being carried off as latent heat of vaporization. At high temperatures, this form of regulation is the prominent one, so that anything which, like a high relative humidity of the air, tends to check evaporation may cause great discomfort and even danger, while, on the other hand, even a slight breeze, tending to increase evaporation, may be a great relief.

These processes collectively constitute what has been called the "physical" regulation of the body temperature, and act through a considerable range of temperature. Necessarily, there is an upper limit beyond which these means of getting rid of heat become insufficient, and the fatal heat stagnation begins. As we go below this limit, the tendency of a falling temperature to withdraw heat from the body more rapidly is met by changes the reverse of those just described, and by their means the outflow of heat is kept practically constant and there is no increase in the amount of heat produced, but rather a slight decrease. As we follow this experimentally, however, we reach a point, known as the critical temperature, at which the possibilities of this physical regulation appear to reach their lower limit. The facility with which the surface of the body eliminates heat cannot be further reduced, and a continued reduction of the external temperature is met by a marked increase in the heat production—the so-called "chemical" regulation. The answer to our initial question, then, is that at or above the critical temperature, the incidental heat production due to the internal work of the body suffices, or more than suffices, to maintain its normal temperature, while below that point, additional body material must be oxidized for this special purpose.*

The critical temperature has been found to vary for different

*Of course, the relative humidity of the air and its rate of movement also affect the result; but since the temperature is the most important factor we may, for simplicity, deal chiefly with this.

animals. For naked man, according to Rubner, it is about 37° C.; for the dog, about 20°C.; for the guinea-pig, about 30° to 35° C. Civilized man, however, ordinarily keeps his immediate surroundings above his critical temperature, either by means of artificial heat or by clothing, or both, so that the regulation of his body temperature is chiefly or wholly by "physical" means. Indeed, there are not lacking indications that he has lost more or less the power of responding to cold by an increased heat production; *i. e.*, the power of "chemical" regulation.

Bearing these facts in mind, we are prepared to consider the relations between the food supply and the heat economy of the body.

It is an observation as old as the time of Lavoisier that the ingestion of food tends to cause an increased heat production, and this observation has been fully confirmed by more recent investigators, notably by Zuntz and his associates, and still more recently by Rubner. This augmented heat production arises in part from the muscular effort of prehension, mastication, deglutition, peristalsis, etc.; in part, doubtless, from the increased chemical activity of the glands of the digestive tract; and in part from the chemical changes involved in the conversion of the nutrients of the food into forms fitted to nourish the tissue. To the latter must be added, in herbivora, the extensive fermentations occurring in the digestive organs.

The quantity of heat thus generated is found to vary materially with the character of the food. Of the recognized classes of nutrients, the proteids cause the greatest relative heat production, amounting, according to Rubner's latest results, to about 31 per cent. of their total heat value; that is, out of 100 calories of energy supplied in the form of food proteids, 31 calories are liberated as heat in the process of digestion and assimilation. For fat he finds an increase of 12.7 per cent., and for sugar 5.8 per cent. The striking effect of proteid food upon the heat production is well established by other investigations, but Rubner's high figure for fat is considerably at variance with earlier results.

In addition to the proportion of the several nutrients, the physical condition of the food is of importance as affecting the mechanical labor of digestion and the nature of the processes going forward in the alimentary canal. Thus, to take an extreme case, the writer has recently shown that in the case of timothy hay, a material consisting largely of carbohydrates and related

bodies, fed to a steer, 37 per cent. of the energy of the digested matter was liberated as heat during digestion and assimilation, while similar (unpublished) experiments on corn-meal have given a percentage of about 20.

In the digestive and assimilative processes, then, we have an additional source of heat to the body. What relation, now, does this bear to the general heat economy of the body as already outlined? Briefly, we may answer, "substantially the same relation as heat from an external source." As already pointed out, the animal body appears incapable of utilizing energy in the form of heat. When it has once been degraded to this form it has escaped from the grasp of the organism. If, then, the body has already a sufficient supply of heat from other sources, that is, if its environment is above the critical temperature, that liberated during the digestion of the food will be of no advantage to it, but must be gotten rid of as an excrement, and at high temperatures may even become an additional burden. Below the critical temperature, on the other hand, the heat arising from the internal work of the fasting animal is insufficient to maintain the body temperature. Under these conditions, as Rubner has shown, the heat liberated in digestion and assimilation may make good the deficiency, thus preventing the oxidation of body tissue for this purpose and so being indirectly utilized. Below the critical temperature, then, the total-heat value of the food may be utilized, in part directly as the chemical energy of the assimilated food, and in part indirectly by preventing the oxidation of tissue simply for the sake of heat production. This is, in fact, Rubner's law of "isodynamic replacement," which teaches that the nutrients of the food, aside from an indispensable minimum of proteids, are of value in proportion to the heat which they are capable of liberating in the body—the so-called "physiological heat values" or "fuel values."

It is the undue extension of this law of isodynamic replacement which is largely responsible for much of the current misconception concerning the relative energy values of foods and the relations of food to heat production. As announced by Rubner, it was limited to relatively small amounts of food, while his experiments were made at moderate or low temperatures. The seeming simplicity of the law, however, combined with the tendency already adverted to to identify heat and energy, have led many writers to assume that the "fuel value" of the food is a measure of its physiological value under all conditions.

As we have just seen, however, isodynamic replacement is the result of a sort of compensation, by which heat arising from digestive and other work is substituted for heat supplied by oxidation of tissue. Consequently, it obtains only within comparatively narrow limits, viz., under circumstances such that there would otherwise be a deficiency of heat. That is, it can occur only below the critical temperature and with amounts of food sufficiently small so that their digestion and assimilation will supply no more than the lacking amount of heat. Outside of these limits, the net physiological value of a food as a source of energy to the organism is measured, not by its "fuel value," but by the amount of chemical energy remaining after the expenditures necessary for its digestion and assimilation have been met. Logically, of course, this is equally true under all conditions, the effect being simply masked at low temperatures and with small amounts of food.

So far as the nutrition of man is concerned, then (and the same is probably true to a large degree of domestic animals), since his surroundings are ordinarily above the critical temperature, the "fuel value" of his food and its actual nutritive value, as measured in terms of energy, are not identical, the former being the greater. The well-fed individual is producing more heat than the actual needs of the organism require. He is engaged in getting rid of heat. His body may be compared to a house in which a fire is burning, the excess of heat being disposed of by opening the windows. Part of this heat arises from the necessary internal work of the organism and is fairly constant in amount (in a state of rest). The other and variable portion is due to the work of digestion, its amount depending on the quantity of food and on amount of energy which must be expended in its digestion and assimilation. The consumption of a small amount of easily digestible carbohydrates, for example, would result in a relatively small heat production, while a large quantity of proteids would greatly increase the loss of energy in this way.

At low temperatures, this additional heat production may be an advantage, enabling the well-fed organism to withstand cold better. The weather may become colder before the windows must be entirely closed and the consumption of fuel increased. The critical temperature of the well-fed animal is lower than that of the same animal when fasting. At high temperatures, on the other hand, this additional heat may become oppressive or even dangerous by adding to the amount which the organism must dispose of

through radiation, conduction and evaporation. A large consumption of difficultly digestible food renders the man or animal less able to endure hot weather, and presumably more liable to those disorders resulting from overheating. Instinct leads us to reduce the amount of food consumed in hot weather and, as Ranke has shown, in very hot weather the amount consumed may even be reduced below the actual demands of the body. Of the two evils, a loss of tissue is chosen in preference to an excessive heat production. Furthermore, proteid foods being those which cause the greatest production of heat, their amount in the dietary should be reduced to the minimum necessary for maintenance if it is desired to limit the heat production, their place as sources of energy being supplied by the carbohydrates and fats.

In brief, then, the food value of a nutrient as a source of energy to the organism is not measured by the total energy which it can liberate as heat in the body, but by the part of this energy which is available to the organism for physiological uses. The remainder of the "fuel value" simply serves to increase the generation of heat in the body, a result which may be advantageous or the reverse, according to the surrounding conditions.

The Promotion of Agricultural Science. *

By Dr. Henry Prentiss Armsby, State College, Pa.

The Society for the Promotion of Agricultural Science was founded in the year 1880, largely through the efforts of a few men, most of whom have now passed to their reward, who saw clearly the necessity for some such organization.

At that time the workers in agricultural science in the United States were few and scattered. While the oldest of the Agricultural Colleges had been in existence for some twenty-five years, these institutions were still comparatively feeble with, in most cases, few students and struggling for recognition. The first Agricultural Experiment Station in the United States had been established but five years before and had been fully taken over by the State two years later. At the date of the foundation of this Society, there existed in the United States three experiment Stations, two university Stations and one private Station, and few means were available for personal contact or exchange of ideas between investigators or for the publication of their results. The U. S. Department of Agriculture was a comparatively small affair, presided over by a Commissioner, and its scientific work was chiefly that of its chemist, entomologist and veterinarian.

The twenty-six years which have since elapsed have witnessed a phenomenal development of agricultural education and investigation, and the young student of the present day can hardly realize the conditions which existed a generation ago. Now, instead of half a dozen Experiment Stations, with an aggregate income of about twenty-two thousand dollars, we have in the United States proper, sixty institutions with a total income for the year 1904-5 of over one and a half million dollars. The U. S. Department of Agriculture has grown from a staff of one hundred and eight persons and an annual income of somewhat over two hundred thousand dollars in 1881,

* Delivered at Twenty-seventh Annual Meeting of The Society for the Promotion of Agricultural Science, 1906.

to a great executive department with a total appropriation for the present fiscal year of nearly ten million dollars. The Land Grant Colleges, too, from feeble and more or less destitute "cow colleges" have acquired an acknowledged and honored position among the institutions for technical education, with a total endowment of over eighty-one million dollars and an annual income of over eleven and three-fourth millions, with faculties aggregating two thousand six hundred and seventy-two, and giving instruction to a total of nearly sixty thousand students, of whom nearly nine thousand are students of agriculture. In place of a few scattered bulletins and reports, issued in small editions, the Experiment Stations and the Department of Agriculture have become great publishing agencies, and instead of it being difficult to find a medium for the presentation of the results of investigations, the difficulty more often seems to be to find suitable material for the numerous publications called for by law or popular demand. Finally, the organic unity of these institutions as a class has been secured through the Association of American Agricultural Colleges and Experiment Stations. Surely this is a magnificent record for a little over a quarter of a century, and the end is not yet.

With this stupendous change in the situation, it might almost seem as if there were no function remaining for a society like this. Are not all these public institutions instrumentalities for scientific investigation in agriculture on a scale and with resources such as to make a private organization superfluous? Is it still necessary to promote agricultural science?

Let us at the outset define our terms. By agricultural science we understand that body of scientific principles, known or discoverable, which underlies and conditions successful agriculture. By the promotion of agricultural science, we may understand the support of any measures calculated to give us a deeper and more comprehensive knowledge of these principles. In other words, it is equivalent to the promotion of scientific investigation in the field of agriculture. Investigation is scientific, as distinguished from practical, when it is undertaken with the prime object of enlarging our knowledge of principles and without immediate reference to practical

applications. Its incentive is the desire to know more rather than the ambition to do more.

Few members of this Society, certainly, will question the fundamental importance of such investigation. They realize the truth of a recent remark by Dr. Welch* of Johns Hopkins at the dedication of the new buildings of the Harvard Medical School, that, "The same phenomenon is exhibited in (medicine) as in all science that the search for knowledge with exclusive reference to its application is generally unrewarded." Research forms the ultimate basis of all agricultural as of all other progress, whether in the school, the college, the correspondence course, or on the farm. I may be permitted to further emphasize this truth by quoting the words of one whose standing both as a scientific investigator and as a successful administrator is universally recognized.

At the Jubilee of the University of Wisconsin, in 1904, Professor T. C. Chamberlain of the University of Chicago said:

"The fundamental and ulterior sources of education do not lie in the conventional schools, but back of them. These sources cannot here be defined at length, but, in a simple phrase, may be said to lie in the great stock of ideas possessed by mankind. This phrase inadequately embraces the whole, but let us agree that it may stand for the whole. In so far as the stock of ideas of a people is narrow, defective and erroneous, on the one hand, or broad, demonstrative and exact, on the other, in so far the fundamental subject—material of education partakes of these qualities. In so far as the sentiments, beliefs, attitudes and activities of a people are narrow, loose and perverted, on the one hand, or free generous and ethical, on the other, in so far education inevitably shares in these qualities. For these are fundamental sources of education. The basal problem of education is therefore concerned with the entire compass of the intellectual possessions of a people, and, in a measure, of all mankind. The special selections propagated in the schools are but a miniature reflection of the total possession, and this selection is usually noble or mean, as the whole is noble or mean.

*Science, Oct. 12, 1906, p 460.

If these considerations are true, the fundamental promotion of education lies in an increase of the intellectual possessions of a people, and in the mental activities and attitudes that grow out of the getting, the testing and using of these possessions."

* * * * *

"The education of the individual does not necessarily lift the education of the aggregate, for if we convey to the rising generation only such ideas as we have inherited, the summit level of education is not raised. There may be diffusion, there may be an evening up, but no lifting of the upper levels. If the intellectuality of the new generation does not rise above that of the old, there is only a Chinese dead level of ancestral propagation."

* * * * *

"To secure laudable progress in the fundamental conditions of education, systematic provisions for scientific research is necessary."

Granting now the need of scientific investigation in agriculture as in other branches of human activity, let us inquire what are some of the conditions which favor or hinder it. A recent writer,* describing the "Needs of scientific men," says:

"We neither expect scintillating 'success,' nor do we look forward to any prizes in the way of highly paid positions. Our needs are mainly two: (1) adequate time for work and (2) a living wage."

After mentioning two instances of the lack of time for scientific research among his acquaintances, he continues:

"The difficulty is intimately connected with the other one, that of the living wage. There is no living wage for *research*; research in pure science is at present a parasitic industry, to borrow a term from the economists. Both of the men I have just referred to get their salaries for doing economic work, and whatever they do in pure science is supported and made possible by the other. A still larger body of re-

*Cockerell; Science, Aug. 11, 1906, p 178.

searchers lives upon the proceeds of teaching, while those who *actually get a living by research* are very very few. The Experiment Stations, even, do not disobey the general rule, for the demand for immediate results of economic value is such that the workers are almost obliged, in the majority of cases, to desist from work of a broad and fundamental character while most of them, of course, have to do a large amount of teaching."

In this last sentence there is indicated the serious danger that threatens agricultural research in the United States. Even a very cursory review of the changes of the last twenty-five years shows a wonderful record of progress on the material and practical side. We have vastly increased our equipment for agricultural investigation and added many-fold to the numbers presumably engaged in it, but is the output of real scientific results, which will stand the test of time, commensurate with the increased facilities?

The agencies for agricultural investigation which have made such a phenomenal growth in the last quarter of a century were at first looked upon with suspicion or distrust by the public. They had to demonstrate their right to be supported from the public purse, and to do this were compelled to take up first the pressing practical problems and to give research a secondary place. But their very success in demonstrating their usefulness, as shown by their increasing appropriations and by the change in the public temper familiar to all of us, threatens to be their permanent undoing as agencies of scientific research. From an attitude of skepticism the public has passed to one of undue credulity, and the Experiment Stations today have need to heed the ancient warning "Woe unto you when all men shall speak well of you! for so did their fathers to the false prophets." Indifference has given place to urgent demands for assistance, and the pressure upon these institutions for facts of immediate practical utility, which shall justify to the public the liberality with which they are supported and lay the foundation for greater appropriations in the future, is so intense as to require unusual courage and breadth of vision on the part of him who will stand for the needs of real scientific investigation.

The ever present tendencies toward premature and sensational exploiting of results, and towards officialism in science, are likewise dangers which need constantly to be guarded against. A recent writer, speaking of the reasons why agricultural science is often discredited with the practical man, says,

"Science, too, is sometimes responsible for another form of apparent contradiction (between the results of science and those of practical experience), many of her representatives being only too much inclined to generalize the results obtained in a special case, and especially to publish prematurely. This error is more or less fostered both by officials and by agricultural organizations. When a report *must* be published yearly upon all sorts of scientific work, whether completed or not, in which case 'results' are naturally expected and planned for, there is produced a literary ballast that is a burden upon scientific work and which carries with it the serious danger that the agricultural public, before which these unripe fruits are zealously spread by the agricultural press (especially in the case of official reports), will feel the evil effects in its purse and will lose its appetite for all scientific results. The subsequent continuation of the investigations then develops the limitations, corrections, and specializations and the unripe conclusions are altered or sometimes even entirely overthrown and admitted to be erroneous. This is most injurious to practical agriculture, and has already led to great losses and brought science into deserved disrepute.

* * * * *

In my opinion it is not at all essential to bring new achievements before the general public with the utmost promptness and to publish as much and as speedily as possible, but rather that all which is published shall be trustworthy and securely grounded, not only by individual investigation, but as far as circumstances demand by the due mention, consideration, or critical discussion of whatever other investigators have previously said and discovered concerning the subject. Nowadays, the haste for publication has made it actually the fashion in many circles to ignore the available literature, or to pirate it, and to act as if one were the first who had laid this egg. It is often the case, too, that

the reader is supplied only with summaries or other average or final figures, while all deeper insight into the course of development and the details of the investigation is prevented by their silent omission. This method of publication is unscientific and superficial, and he who uses it, especially when he avowedly substitutes the authority of his name, does not perhaps realize how great is the presumption toward the reader of which he is guilty in such a method of presentation.

The unholy thirst for notoriety, too, has also struck deep root in agricultural science and has developed such vigorous shoots that it has become a shame for those who are guilty of it and has fairly compromised our science. Unfortunately, no one has yet been found to duly scourge and pillory the false and unscientific nature of these methods.

All these growing evils are signs of degeneration. Let us guard ourselves against further cultivation of appearances and externalities. It is high time that modest, quiet, genuine work should take the place of this haste and false ambition, for agricultural science, as a relatively young science, stands in much too exposed a position, both in relation to other sciences and to agricultural practice, to permit itself such laxities."

I quote these words from an article* by Prof. Von Rumker of the University of Breslau in Germany.

Moreover, the Agricultural Experiment Station in the United States has developed to a degree almost unknown in the land of its birth.

Twenty-five years ago the conception of an Experiment Station was that of a comparatively small institution exercising a police control over the manufacture and sale of certain agricultural products, notably fertilizers, and carrying on scientific research largely by laboratory methods. To a considerable degree this conception still obtains in foreign countries, but in the United States the Stations have had an unexampled development. They are rapidly growing into great departments, touching the practice of agriculture in their several localities at all points, and the leaders in a vast

*Landwirtschaft und Wissenschaft; Berlin, Parey, 1905.

propaganda for the elevation of rural life. We feel a just pride in this peculiarly American development of an adopted institution, and in the large measure of success which has attended it, but it would be foolish to shut our eyes to the accompanying dangers, and not the least of these is the drying up of the sources of power and inspiration by the failure to duly promote science along with practice. Not only does the pressure for results tend to the subordination of the scientific to the practical, but the management of these great institutions is making heavier and heavier demands on the time and energy of some of our best men. In fact, we seem to be developing a new type of leader in agriculture, comparable with the university president, who is primarily an administrator and whose chief function is to set other people at work. All honor to the successful administrator. Through his administrative work he is often a most efficient promoter of science. But let us not forget also to see to it that our system provides due honor and reward for the successful scientist and investigator. While the American type of Experiment Station is an admirable institution, and while the popular work of the Stations and Colleges is of vast importance and benefit, we must not forget that it all rests on the truths of science, and that unless science makes progress the popular work will soon be marking time.

The year 1906 witnessed a notable forward step in the development of agricultural investigation. The passage of the Adams Act has doubled the United States appropriation to Experiment Stations, nominally in five and practically in four years. This fund differs from the Hatch fund in that the Act specifies that it is to be used only for "Conducting original researches or experiments." It is not too much to say that the great opportunity offered by the passage of the Adams Act, which has been the occasion for so much congratulation, will, like every other opportunity, prove also to be a day of judgment for the Stations, in that it will reveal to all men their conception of original research, and demonstrate whether or not they have a broad fundamental grasp of the idea of investigation. Differences of opinion regarding the application of this fund are already apparent. The Stations stand at the parting of the ways. Will they simply add

demonstration to demonstration, propaganda to propaganda, or will they grasp the opportunity to dedicate this new fund sacredly and irrevocably to original scientific research, broadly conceived and liberally executed.

I shall, no doubt, be characterized as an idealist; as failing to recognize or appreciate the need and the demand for popular work. An idealist I am and such I hope to remain, but I too, know something of that desire for results and of that lively sense of appropriations expected which seldom fails to make itself felt by the Station administrator. The situation is by no means without its difficulties, especially for those Stations which exist to so large an extent under pioneer conditions. Were it otherwise, there would be little occasion for these remarks. The problem calls for strong men with an abiding faith in the fundamental and ultimate importance of scientific research. There is still need for the promotion of agricultural science. Times have greatly changed since a dozen gentlemen met in Boston in August, 1880, and founded this Society, and some of the functions on which emphasis was then laid are now of less importance or have been otherwise provided for, but the great underlying purpose of the Society, as expressed in its name, far from diminishing in importance has become even more vital to real progress.

What, then, may a voluntary organization, such as this, hope to do to promote agricultural science?

At no time since the Society was founded has there been greater need for maintaining and raising the ideals of what science is and of what constitutes research. We are suffering today from a low and inadequate conception of scientific investigation. Now the conception of scientific investigation which is popularly current at any time depends very largely upon the attitude and ideals of the men of science themselves. The stream rarely rises higher than its source. It is of prime importance, therefore, that those professionally engaged in investigation in agriculture, whether in the Experiment Stations or elsewhere, should cherish a high ideal of their functions in the body politic, and a high standard of professional and personal obligation. How can such ideals

be more effectively maintained than by association. Scattered over three million square miles, and more or less isolated, we inevitably feel in our daily work the drag of the commonplace, the tediousness of the necessary drudgery which makes up such a large part of investigation, and the temptation to cater to popular applause. What greater inspiration can we have than that which comes from an annual gathering such as this, where we meet, not as chemists or botanists, or entomologists, or directors, but simply as seekers after truth? Is not the mutual support, the discussion, the friendly criticism, which we encounter here a priceless factor in promoting agricultural science? In the conventions of the Association of American Agricultural Colleges and Experiment Stations, we meet officially, and seem tending more and more to the discussion of official and administrative problems. It is well to retain a meeting place frankly devoted to idealism.

But I believe the Society may have other functions besides maintaining the ideals and strengthening the enthusiasm of its members. While it is essential that we maintain right ideals ourselves, it is equally important that we secure their acceptance by others. Few of us are so fortunate as to be able ourselves to defray the expenses of our own investigations. Most of us are dependent for the necessary funds upon the approval of Boards of Trustees or other superior officers, or, since these usually represent the public, we may say that we are dependent upon popular approval or at least tolerance. That research may take its rightful place, the public must come to understand better than it does the nature of research and its importance from the point of view of the general welfare. Should not individuals and societies which stand for the promotion of science, while giving no less attention to specific results of investigation, take greater heed to the formation of an enlightened public opinion? We listened with pleasure and profit this afternoon to a discussion upon agricultural science in the Experiment Stations. Might it not be possible in the future to attract greater audiences to such discussions, and by means of suitable publication to bring them before the larger public? I feel sure that all legitimate influences ought to be brought to bear, whether in this or in other ways, to secure a generous and proper recog-

ognition of the importance of real scientific investigation in the work of our institutions for agricultural education and experimentation.

But such education of public opinion cannot be effected in a month or a year; it must be a work of time, a gradual leavening of the lump. For the present, we can hardly expect otherwise than that the practical, so-called, will predominate over the scientific in institutions supported by public funds. We are led to ask, therefore, whether any more immediately effective measures for the promotion of agricultural science can be devised.

Our minds naturally turn, in this connection, to the much discussed question of the endowment of research. During the last few years, we, along with others, have applauded the devotion of vast sums to this purpose, such as, to name two conspicuous examples, the endowment of the Carnegie Institution of Washington and of the Rockefeller Institute for Medical Research. We have rejoiced at the testimony afforded by these magnificent gifts to the estimate put upon the value of science and scientific investigation by hard-headed, successful men of affairs. We would not, if we could, subtract one dollar from the sums assigned by these and other like foundations to the support of any line of scientific inquiry however abstruse. At the same time, we cannot but regret that the great basal industry of this, as of every civilized country—the one which not only overtops all others in magnitude as measured in terms of money, but the one whose followers constitute the great conservative force of our national life—has thus far practically failed of recognition, and that the claims of agricultural science as a field for research have not thus far seemed to appeal to our men of wealth. I can hardly believe that this state of things will continue indefinitely. Wealth almost incalculable is being created annually by the American farmer, not for himself alone but as well for the great transportation and manufacturing interests whose prosperity depends so directly upon his. Is it not reasonable to anticipate that if the importance of fundamental research in this field were properly set forth, free from the suspicion of personal interest, as it might be by a society like this, the Carnegie or the Rockefeller of agri-

culture would in due time appear, and that the great endowed universities would find a place for it in their programs?

These, then, are some of the larger objects which, as it seems to me, a Society for the Promotion of Agricultural Science should set before itself:—

First, to aid in maintaining among our investigators in agriculture the highest ideals of scientific research, and to help to furnish the inspiration for the pursuit of these ideals.

Second, to seek to educate the public to a greater appreciation of the need for scientific investigation into the underlying principles of agriculture and to a realization of the practical benefits flowing from it, and thus to promote the cause of agricultural science in the Experiment Stations and kindred institutions.

Third, to seek to impress upon university authorities, and upon wealthy donors, the claims of agricultural science to recognition as a most promising and attractive field for the endowment of research.

Is it not by setting before ourselves ends like these, even though they may seem somewhat utopian, that we shall most effectively promote agricultural science under existing conditions rather than by simply meeting annually to read a few technical papers, too often prepared from a sense of duty or at the solicitation of the Secretary, and paying a tax of two or three dollars to cover the cost of publishing them to an unappreciative world?

Finally, if the ideas which I have been advancing be not entirely quixotic, they suggest, to my mind at least, a radically different basis of organization from that which has prevailed hitherto.

At the outset, membership in this Society was limited to forty and the avowed purpose was to include only those who had already attained some degree of distinction in agricultural science. The idea in the minds of the founders, although nowhere perhaps clearly expressed, plainly was to make membership in the Society a distinction to be coveted. It was to be an American Academy for agriculture, a sort of "Forty immortals." Subsequently, the limits of membership have been

greatly enlarged, yet in general the original conception has been adhered to, although not without struggles and heart burnings. That conception was a high and worthy one, and that it has contributed notably to the promotion of agricultural science none can doubt. All honor to the men who at that early day embodied it in a concrete form.

But there is no impiety to their memory in asking whether the original form of organization is that best adapted to the changed conditions of the present day. Personally, I do not hesitate to say that I question this.

The spirit of science is democratic and not aristocratic. In upholding her interests we need the help of everyone who has seen and loved her fair face. The man who has devoted half a lifetime to her service may be assumed to know and prize the modest rewards she offers. It is the young man, at the threshold of his career, dazzled by the glittering promises of business or commercial life, that we need to reach. If the Society's influence is worth anything—if it affords any stimulus to worthy endeavor in the search after truth for its own sake—should not he especially have the benefit of it?

Moreover, why should we despise the aid of the man of affairs? If the promotion of agricultural science is also the promotion of the general weal, should we not rather welcome him as a new and powerful force through which to influence public opinion?

In brief, if the Society accepts a comprehensive view of its mission, should it not make its basis of membership correspondingly broad, imposing no test except that of belief in the purposes of the organization and willingness to aid in forwarding them? It would still be possible to make a distinction in membership which need not be invidious, between those professionally engaged in agricultural science and those merely interested in its promotion on broad grounds of public policy, while the effectiveness of the Society as an agent of propaganda would be immeasurably increased by such a broadening of its membership. The advantages of mere numbers, too, are not altogether to be despised. A larger membership and more ample means, would bring within the range of possibility various means of advancing the purposes of the

Society which now are entirely beyond our reach. The question of publication, for example, might present quite a different aspect under such conditions. The offering of prizes for the investigation or literary discussion of specified topics, the recognition by medal or otherwise of specially deserving investigations, even small grants in aid of research, loom up dimly on the horizon of possibility, but cannot be further discussed here.

I am well aware that these suggestions may appear revolutionary. I have little faith in revolution as a means of progress, but they have occasionally been unavoidable. We may as well frankly face the fact that for several years our Society has been groping for a mission and that its meetings have been supported more or less from a sense of duty. I am not so presumptuous as to assume that I have found that mission. If my words serve to stimulate discussion and reflection concerning the functions of the Society, they will accomplish all that I have any right to hope. True we should beware of losing the substance while grasping the shadow, but on the other hand tradition should not blind us to the changed conditions confronting us. Are we not imperatively called upon to attempt in some way to make the work of this Society such that the leaders of agricultural progress shall feel it worth their while to contribute to it liberally of their time and energy. If we can solve this problem we need have no apprehensions regarding the promotion of agricultural science.

Research as a Career.

PRESIDENTIAL ADDRESS.*

**By Dr. Henry Prentiss Armsby, Ph. D., LL. D.
State College, Pa.**

In the address which I was privileged to present before this Society at its last meeting, I urged with such force as I might that the promotion of agricultural science is equivalent to the promotion, by such means as are at our command, of research in agriculture. I attempted to suggest some ways in which this Society might make its influence more largely felt in stimulating real scientific investigation of a high order and in enhancing the popular appreciation of the necessity for and the value of such investigation, to the end that it might receive the necessary moral and financial support.

The months which have elapsed since that time have but strengthened my conviction of the importance of such promotion of agricultural science. As the education of the American farmer progresses he is feeling less need for and less patience with elementary, superficial experiments and demonstrations. Useful as these have been in the development of our agriculture, their day is passing. Our institutions for agricultural research have entered upon the serious problem of extending and compacting our knowledge of the fundamental principles upon which successful practice must be based. Their work in the future, if they are to justify themselves, must be increasingly of a scientific and even abstruse character, and such research must be amply supported financially and must be allowed the time and continuity necessary to secure valid results.

That the public confidence in the ultimate outcome of scientific investigation in agriculture as undertaken in this country is great, and its future support assured, is clearly demonstrated by the rapidly increasing appropriations made

* Delivered at Twenty-Eighth Annual Meeting of The Society for the Promotion of Agricultural Science, 1907.

to it by both the national and state governments. The recent passage of the Adams Act, in particular, with its stringent requirement for the application of the fund to original investigation augurs well for the future. At the same time, it is equally true that the researches of any publicly supported institution must keep fairly close to the prospect of definite returns. There is a considerable range of abstract research, promising less immediate results, which can be cultivated only to a limited extent by such institutions. The endowment of the more recondite forms of agricultural research I still believe to be of the greatest importance in assuring ample time and security of support for work of this character, and I believe that such endowment will come, as it has for other lines of scientific inquiry. A subject of such fundamental sociologic and economic importance cannot long remain an exception.

Tonight I ask you to consider with me for a few minutes an even more important aspect of the problem of the promotion of agricultural science and one for which possibly the immediate outlook is not so hopeful. We all realize when our attention is called to the matter that the central factor in research is the man. Endowments, laboratories, appliances are secondary and exist and are useful only because and to the extent that they aid the man in his search for truth. This is an elementary conception but I fear we are all prone at times to lose sight of it. It is well to discuss methods of securing financial support for scientific investigation and means of impressing upon the public its importance, but in doing so we are inclined unconsciously to assume not only the present existence of an adequate body of investigators, but that their number like that of the operatives in a factory may be indefinitely increased as occasion arises. This seems hardly a rational procedure in view of the fact that the demands of this work are bound to increase. If we do not expect appropriations to grow by their own inherent energy, and if we undertake to study and improve the organization of agricultural research, is it not the part of ordinary prudence to take thought also for the training of the men who are to meet these increasing demands for agricultural investigation

and to replace those now active in the work? We have no cause to be ashamed of our investigators as a body, but should we not see to it that they have some spiritual progeny?

I raise, therefore, three questions: First—What should be the training of the investigator in agriculture? Second—What are the most effective means of acquiring this training? Third—Are the conditions surrounding research work in agriculture such as are calculated to attract qualified men to it and to induce students to engage in definite preparation for it?

These are large questions, of fundamental importance to the future of research in agriculture. He would be presumptuous, indeed, who should undertake to answer them on the basis of his own knowledge, and especially within the limits of one address, but the mere formulation of them may not be without its use. Certainly, it has seemed to some of us that the material basis of research has at present a tendency to outrun the supply of those qualified to utilize it, and that there are too many instances of mediocre men feeling about for subjects of investigation or taking up irrelevant or petty questions. If this impression be correct, the situation is a serious one and calls for prompt action to avert the danger of a collapse.

In considering these questions we must recognize at the outset that there are grades of research. I quote an already frequently quoted paragraph from the address of Dr. William H. Welch at the dedication of the buildings of the Harvard Medical School.

"On this creative side of university work men count for more than stately edifice and all the pride and pomp of outward life. Research is not to be bought in the market place, nor does it follow the commercial law of supply and demand. The multitude can acquire knowledge; many there are who can impart it skilfully; smaller but still considerable is the number of those who can add new facts to the store of knowledge, but rare, indeed, are the thinkers, born with the genius for discovery and with the gift of the scientific imagination to interpret in broad generalizations and laws the phenomena

of nature. These last are the glory of a university. Search for them far and wide beyond college gate and city wall, and when found cherish them as a possession beyond all price."

The occasional genius, however, may well be left out of our present consideration. Like St. Paul, who said of himself, "Necessity is laid upon me, yea woe is me if I preach not the gospel," so the genius in science is driven by an inner compulsion to search out the hidden things of nature. With this exceptional man the only question is how to make the conditions surrounding him such as to render his work most effective.

For most of us, however, a more modest rank must suffice. As Professor Cattell somewhat pathetically remarks in his discussion of American Men of Science, "Very few of those in this list of scientific men will be given posthumous consideration." Nor need this fact unduly sadden us. There are diversities of operations in the body scientific as in the body spiritual. The great bulk of the work of science in all departments is done by the plodding, faithful seekers after truth rather than fame, and the promotion of agricultural science depends after all quite as much on the patient, conscientious labors of the trained and competent investigator, each in his field, as on the occasional brilliant generalization of the exceptional man. Genius is heaven sent and we do well to reverence the gift of the gods, but talent we may hope to train and foster, and it is talent rather than genius on which we must depend for the work-a-day progress of our institutions for agricultural research.

1. What should be the training of the investigator in agriculture? Aside from that general training necessary to every educated man, there are, I think, two elements to be considered. The investigator in agriculture, if he be a real investigator, is a student of science. He is not a mere observer of nature or of practice; still less, one whose prime motive is the immediate application of his results to an increase of the profits of farming. He is not content with showing that variety A is better than variety B; with demonstrating that better balanced rations may save so many mil-

lion dollars yearly to the state; with showing that the productiveness of the soil may be increased so much by a certain system of farming. All these things may be well worth doing but it is essential that we distinguish, to quote the words of Dean Davenport, between research and "a good thing." The investigator is one who by impulse and by training seeks to go beyond these facts and to trace out the causes of phenomena, the hidden relationships which bind them together. It would seem self-evident then that the first requirement regarding the special training for such work must be that it be scientific. It should rest upon a broad and severe training in science, including actual work in research under the direction and inspiration of an experienced investigator. The student should not merely acquire a knowledge of the facts of science but should saturate himself with the scientific habit of thought and work. However practical the purpose of his future experiments, their methods must be scientific. This, of course, implies specialization, yet investigation in agriculture in particular covers such a broad field and is related to so many sciences that too early specialization should be avoided.

But while the first requirement of the agricultural investigator is this severe scientific training, it must not be forgotten on the other hand that his investigations are to be for the benefit of agriculture. The language of the Hatch and Adams Acts may well be our guide in this respect. Section 2 of the Hatch Act by necessary implication limits the legitimate work of our experiment Stations to "research or experiments *bearing directly on the agricultural industry of the United States*," and Section 1 of the Adams Act employs the same language to qualify the original researches or experiments which may be undertaken under its provisions. However lofty the aim of the investigator, he must take care that his feet rest squarely and solidly on mother earth. Too many instances of futile effort on the part of the purely scientific man to serve agriculture are familiar to us all to require any special emphasis on this point. The object of the agricultural investigator is not the increase of knowledge for its own sake. Indeed, I confess to a doubt as to the worthiness

of such an ideal in any investigator. Let us by all means strive to increase knowledge, even of matters seemingly remote from practical concern, but let us do this, not for the mere satisfaction of mental curiosity nor for the increase of our own intellectual complacency, but because we are persuaded that in so doing we are rendering real even if unrecognized services to mankind. Certainly, the agricultural investigator in the United States is bound to see to it that his projects bear some definite relation to the actual problems of agriculture, which is by no means the same thing as saying they must have an immediate practical application. Plainly, then, the agricultural investigator must have an acquaintance with the practical problems and conditions of agriculture, as well as a training in the methods of science.

2. How may the prospective investigator in agriculture best acquire the necessary combination of scientific discipline and practical knowledge?

Our thoughts naturally turn in this connection to the agricultural colleges. Neither the conception of the agricultural college nor its function in the scheme of agricultural education are as yet altogether clearly defined. Historically, the purpose of the agricultural college has been to prepare men for the business of farming, and the success of these institutions is still largely judged by the general public from this standpoint. For the quarter century following 1862, practically the only idea of agricultural education that was in men's minds was that of a course at one of these colleges—these courses varying somewhat widely in character but being supposedly at least of college grade. In later years, our conception of the scope and methods of agricultural education has greatly broadened. We have successively added to the system secondary courses, trade courses (especially dairy courses), various forms of extension and demonstration work, and finally are making a beginning in providing for primary education in agriculture. While we still regard a collegiate education as desirable for the farmer, we nevertheless recognize that the ranks of educated practical farmers must be largely recruited from these other sources.

With this enlarged conception of agricultural education,

some change of emphasis in the agricultural college seems called for. As these other means of agricultural education develop, the function of the college will, I am convinced, tend more and more to become that of the training of leaders—owners or managers of large estates, public agricultural officials, teachers, and not least, investigators. That all these need special training in addition to that which may suffice for the practical farmer will not be disputed, and it seems to me equally indisputable that the agricultural colleges should supply this training, but there has seemed to be a certain degree of hesitancy on the part of the colleges to recognize this as their special field of work. They are passing through a transition stage and the traditions of the past are still powerful, while they are perhaps peculiarly subject to the temptation that besets all technical education to sacrifice ultimate power to immediate efficiency.

In its relation to the undergraduate training of the future investigator, the question is largely one of the quality of the training given by these institutions. They unquestionably familiarize their students with the practical aspects of agriculture and so furnish to a good degree one of the two elements required in the investigator, but how far do they impart to their graduates the spirit and temper of the investigator? Here again we must take account of conditions as they exist. Agriculture as a discipline is a comparatively new subject. Much has been done within the recent past to bring it into pedagogic form, yet large portions of it are still of necessity taught as information subjects. This seems unavoidable under present conditions, yet it has its unfortunate effects upon the student, which are only partially minimized by his training in the sciences related to agriculture. One of the most urgent needs in the training of investigators is greater emphasis upon the teaching of the science of agriculture to undergraduate students, and this again can be fully efficient only as the foundations of that science are broadened and deepened by the labors of the investigator. I make these comments in no pessimistic spirit. Our agricultural colleges are doing, on the whole, admirable work, and if they can avoid too great emphasis upon the practical applications

of science, their graduates should furnish our chief supply of agricultural investigators.

No one expects, however, that the average baccalaureate will be a qualified scientific investigator in more than the most limited sense. His time has been fully occupied in laying the foundations and he is just ready to begin his real training for research, which must be essentially graduate training. Hitherto, the function of graduate instruction has been but slightly developed in our agricultural colleges and their condition in this respect has been fitly characterized by Prof. Bailey as "Headless." In the past, graduate training in agriculture, except as it has been secured in foreign institutions, has been gained chiefly in the actual prosecution of research in our experiment stations and departments of agriculture. We have been practicing an apprenticeship system. Agricultural research in this country has grown with such tremendous strides that every graduate showing fair promise of ability in this direction has been eagerly caught up by these institutions. Almost as an incident, and without distinct purpose or plan on their part, they have become our agricultural university and their assistants have been our graduate students. Where those in charge of the work have been themselves thoroughly trained scientists, the method has worked fairly well, but in the rapid expansion of the work of research, very responsible positions have perforce been filled by men whose scientific training was not of the highest grade, however great their practical qualifications. In such cases it has been natural that the scientific training of the assistant should be more or less inadequate and the results have not always been the most fortunate. The time will soon come, if indeed it be not already here, when the provision of adequate graduate training in agriculture must engage our serious attention. It is a most hopeful sign of the times that the Association of American Agricultural Colleges and Experiment Stations has definitely assumed the responsibility for the continuance of the Graduate Summer School of Agriculture, and the relatively large attendance at both the sessions of that school shows that the need for graduate study is widely felt. It is a very promising beginning, yet only a be-

ginning. Even its most ardent advocates or those most intimately associated with its development would not for a moment claim that it can fully meet our fast coming needs or supply that systematic training in investigation which is requisite if the personnel of our research institutions in agriculture is to reach the degree of efficiency demanded by the problems of the future. It seems to your speaker high time that the stronger colleges began the earnest consideration of the question how the services of the many talented and able men in the faculties of our agricultural colleges may be brought to bear on the post-graduate education of our future investigators, not merely for a week or two at a summer school but in the daily work of laboratory and seminar. A present difficulty, of course, lies in the somewhat limited number of students in any one institution desirous of such opportunities, yet it would seem that a system of inter-university credits for work done, with perhaps the occasional exchange of professors, might help to meet the difficulty.

Naturally such graduate work, if undertaken, will at first be closely affiliated with the experiment stations, yet there is a certain distinction. The first duty of these public institutions for agricultural research is to produce results. They are conceived and organized primarily for this purpose and not for graduate instruction, and while the latter in the large view is perhaps quite as important as the former, in any conflict of obligations it must give way. Under conditions as they exist today, I am inclined to the belief that it would be to the great advantage of our future research work if as many as possible of those contemplating entrance upon it were to spend such time as they could at a non-agricultural university, where research is carried on with a more distinct view to its influence in training the student and where a changed atmosphere and conditions, and contact with diverse lines of investigation, tend to give the student a broader outlook. If his interest in and sympathy with agriculture are so weak as to be dissipated by such contact with university life, his value to the cause of agriculture in any case is questionable. If such a course is impossible, then let the student seek a position under some competent investigator, where he can take part in and

imbibe the atmosphere of research, and let him regard this as part of his post-graduate training and if necessary pay the price by accepting a low salary for a year or two. The experiment stations should count it part of their duty to encourage such training by giving preference to such men in their appointments.

3. Are the conditions surrounding research work in agriculture such as are calculated to attract qualified men to it, and to induce students to engage in definite preparation for it?

As I see it, three requirements must be met.

Perhaps the most important of these is the prospect of opportunity for independent work involving both responsibility and credit for results. Naturally the young assistant must usually begin in a subordinate position. This is both unavoidable and healthful. In the execution of any considerable scientific undertaking, a certain amount of routine work must necessarily be done. Weighings must be made day after day; measurements must be taken; plots must be inspected; bacteria must be counted; chemical analyses must be executed; data must be recorded and computed. These are the stones with which the structure of research is built up, and unless they be quarried from the enduring rock, and laid four-square to the winds of heaven, there is danger that the whole edifice may come tumbling about our ears. Much of this work naturally falls to the man occupying a subordinate position, nor should he object to this. On the contrary, it is a valuable discipline to him. He is learning to use the tools of his trade; he is seeing how these separate items are organized and marshaled in the attack upon the problem under investigation.

No one who has been responsible for the organization of such an undertaking, however, can fail to recognize that the necessity for routine work brings with it danger. There is a strong temptation to organize the investigation on what may be called the factory system; to assign to each man some one class of duties in which he may become perfect by repetition, and to make assistants and appliances alike simply cogs in the

machine for turning out scientific results; and the temptation is perhaps the greater, the more efficient the organizer and the broader his grasp of the problem. But such organization, while perhaps the most efficient as regards quantity of work and well adapted, for example, to the execution of control analyses, must utterly fail to develop that *esprit de corps* which is essential in investigation and in the end must seriously affect the quality of the work. Team work is as requisite in research as in athletics, and not the least of the duties of the captain is to make each man feel that his work, however humble and monotonous, is an essential and integral part of the whole. To the extent to which this can be accomplished, routine ceases to be drudgery and the worker becomes alert to bring his contribution to the whole as near perfection as possible.

But the beginner in research should see before him a prospect of something better than routine. As he acquires experience and power, there should open before him the possibility of attaining a position of higher rank and greater responsibility. While it is true that at present there is no lack of opportunities for competent men, nevertheless, this is a point which may well be born in mind in considering problems of organization. The tendency of the present time seems to be toward relatively large and highly organized agencies for agricultural research. From the point of view of administration this is a natural tendency, yet from the point of view of research it may have unfortunate consequences. If the head of the organization be himself an investigator his time and strength tends to be withdrawn more and more from his highest work to the problems of organization and propaganda. On the other hand, if the head of the organization be an administrator pure and simple we run into the opposite danger of a lack of sympathy with the view point of the scientific investigator and of a more or less bureaucratic organization. Administration, of course, we must have. On the other hand, the real investigator must be close to his work and able to give it the major share of his time and strength. It is as true in science as in religion that no man can serve two masters. Without attempting any dis-

cussion of the administrative side of the question, I am strongly of the opinion that each group of workers undertaking a definite field of research should in some way be allowed a large degree of independence in their operations with of course the corresponding responsibility which can only come with freedom. How this may be best combined with a proper coordination of all the lines of work of an experiment station, for example, and with effective financial administration, is a question lying outside the scope of this address.

A practically if not formally autonomous organization of a limited line of research would seem to hold out distinct advantages to the younger workers. Such an organization is likely to comprise comparatively few individuals, who are brought into close personal touch with each other and with their chief. The latter, if he grasps his opportunity, will be far less the director than the inspirer of the work. In such an organization the formal bonds of authority rest lightly, or give place to the comradeship engendered by the pursuit of a common object. Not only do such conditions lighten the burden of routine work, but in the stimulating atmosphere of research the powers of the subordinate have every opportunity to develop and manifest themselves. In short, it is in this way that the university function of the research institution is most effectively performed and the training of the young worker in the method and spirit of scientific investigation most rapidly advanced. Our agricultural colleges will do well to consider whether liberally supported departments of real, fundamental scientific research will not be of the highest value from the educational standpoint in furnishing graduate training for students in addition to their importance in building up agricultural science. Moreover, a decentralized organization of research, while not perhaps increasing the number of positions to be filled, nor diminishing the amount of routine work to be done, does increase the number of virtually independent and responsible positions. Considerations of formal organization should interpose as few obstacles as possible to the development of the individuality of the promising investigator. This is the soul of research; the organization but the body.

Another condition, closely related to the above, which must be fulfilled, if research in agriculture is to be made permanently attractive to able men, is what we may call in a somewhat extended sense academic freedom. The competent investigator should be responsible for his mature scientific conclusions primarily to his own conscience. Crudeness and haste may perhaps tend to mark the work of the young investigator, but under any wise and judicious administration these failings can easily be remedied, and their overcoming made a part of the training of the man, with no sacrifice of freedom. Premature and sensational publication and the search for newspaper notoriety, are of course to be deprecated and if necessary suppressed, but anything like suppression of results because they do not accord either with supposedly established views or with preconceived notions of a superior officer is not only fatal to the interests of research itself but likewise to the supply of competent investigators. No man with the true spirit of the investigator will consent to accept a position in which the results of his investigations are prescribed in advance.

I am glad to believe that there is comparatively little of this spirit in our institutions for agricultural research, and that the cases are rare in which any sane and well considered conclusions are not assured of a hearing. Indeed, I am inclined to believe that our danger lies rather in the opposite direction; in the too ready acceptance of novel or striking conclusions, and the lack of adequate criticism and discussion of results announced. It is a necessary corollary of the doctrine of freedom of investigation that there shall also be freedom of discussion, and that if a man's scientific utterances are not dictated by his superior officers neither shall he expect to be defended by them from the critical judgment of his scientific peers. I am not now referring to personal attacks, or the impugning of scientific or professional veracity, but to the deliberate, objective judgment of experts upon the quality of a man's work and the validity of his conclusions. If he cannot justify himself before this tribunal, he should not cry to Jove for help. One of our most serious deficiencies at the present time is the lack of a suitable medium for the judicial

criticism—just and appreciative, but also unsparing—of publications in agricultural science, but it is far easier to see the difficulty than to devise a remedy.

Finally, we have to inquire what rewards research in agriculture offers. First, there is the question of the pecuniary rewards. No one under present conditions expects the work of research to be brilliantly successful financially. While science is coming to be more and more largely recognized as lying at the basis of our material civilization, it is still the inventor, rather than the investigator, who reaps the large pecuniary rewards. The investigator, however, may fairly claim a living wage, and this means, in his case, not simply provision for his physical needs but for his mental growth as well. He must have books. He must maintain membership in learned societies, and attend their meetings. He must, if possible, travel. He must maintain a style of living measurably comparable with that of the classes of society into which he is naturally thrown. He may even wish to rear a family.

In the hope of obtaining some data regarding the actual compensation of agricultural investigators in this country, which might be, at least, suggestive, I have addressed inquiries on the subject to the directors of all the experiment stations. Thirty-seven of these have been kind enough to reply, more or less fully, to these inquiries. The questions related to the salaries paid to the scientific staffs of the Stations, excluding, on the one hand, the director, whose salary is presumably determined, in part, by his executive ability, and, on the other hand, those persons whose duties are of a purely clerical or mechanical nature. They included college as well as station salaries. It is obvious that returns secured in this somewhat hasty and informal way cannot be regarded as in any sense authoritative, yet some of the results may not be without interest.

It appears that the average total salary of 509 individuals is \$1,442 per year. In the case of 489 of these, \$926, or 64 per cent of the whole salary, was paid by the experiment station. Somewhat more instructive is the range of salaries. The average salary of the thirty-seven persons reported as

receiving the maximum in their respective institutions was \$2,269. The average salary of the thirty-two persons receiving maximum Station salaries was \$1,605. The largest total salary in the list is \$4,000, paid wholly by an experiment station. The next highest total salary is \$3,450, while the next highest salary paid by an experiment station is \$2,600. The lowest salary in this list is \$1,020, the next lowest, however, being \$1,500. Turning now to the other end of the series, the thirty-six individuals reported as receiving the minimum salaries averaged \$667, and the twenty-nine reported as receiving minimum station salaries averaged \$642. The highest minimum salary in the list is \$1,200, while amounts as low as \$100 are reported, evidently covering only partial or temporary service. These figures confirm fully the general statement made to me by Director A. C. True, of the Office of Experiment Stations, in response to an inquiry, as follows:—

“The salaries of mature experts in our stations range all the way from a merely nominal sum, given for consultation services, or supervision of some limited investigation, up to \$4,000. Where an expert's service is wholly given to his college and station work and he has the rank of professor, but does not act in an administrative capacity, the salary ranges from \$1,500 to \$4,000. Salaries of \$1,800 to \$2,000 are quite common and represent what may be called the average. There is a general tendency to raise salaries, and \$2,500 is a much more common figure than it was a few years ago.”

Apparently, then, the young man looking forward to a career in agricultural research may expect to begin his service at a salary of from \$650 to \$700 per year, or if he is fortunate in his institution, may receive as much as \$1,200. It appears, also, that nearly all of this is likely to be paid by the experiment station. In other words, the figures confirm the general impression that it is the younger and less well trained workers who are employed exclusively, or chiefly, in station work. If an average young man, as he grows in experience and usefulness he may expect to reach the average salary of \$1,400 to \$1,500, by which time, however, something

like one-third of his energies will be demanded by the work of instruction. As he approaches the higher grades of the service, he may anticipate a salary of from \$2,000 to \$2,500, of which perhaps 40 per cent will be received for teaching work, while \$3,500 to \$4,000 appears to be the upper limit, with the exception of a comparatively few more highly paid executive and administrative positions.

On the whole, these data seem to indicate that the work of investigation in agriculture is paid much on the same scale as the work of instruction in our colleges and universities, although naturally no exact comparison is possible. The weak point appears to me to be the comparatively small salaries paid in the lower grades of the service. With the growing call for men in other lines of agricultural and scientific work, the stations are in serious danger of finding their lower ranks filled with the "culls" of our agricultural graduates.

Naturally few things are less satisfactory than a discussion of the proper compensation for professional or similar services. There are few of us I presume, who are quite sure that our abilities are as fully recognized pecuniarily as they should be, or who could not find many uses for even a small advance in salary, while, on the other hand, there are few of us who, if compelled to do so, could not subsist on less than we are now receiving. Commercial standards are not altogether applicable, yet this much may safely be said, that if the work of research in agriculture is worth doing at all it is essential that its money rewards be sufficient to prevent the pressure of pecuniary needs from forcing capable and competent men into other lines of work, a tendency which has not been entirely lacking in recent years.

But the pecuniary rewards of research, like those of any other career, are or should be secondary. The man who simply works for his wages is equally to be commiserated, whether his work be in business, in science or industry; whether his wages be measured by dollars or by millions. To the man of high ideals not a small part of the attraction of a career of successful research lies in the very fact that its

largest rewards are immaterial. Leaving out all questions of pecuniary recompense, or of possible fame, the rewards of the searcher after truths are large. The satisfaction of worthily exerting worthy powers is after all one of the highest pleasures which most men can enjoy. He who can feel as he nears the end of life that his work has been of real service, however humble, to mankind—that he has assisted in building up instead of tearing down—can look toward the end with confidence.

Such satisfaction, it seems to me, is peculiarly the share of the agricultural investigator at the present time. This country seems to be just beginning to realize the tremendous sociological importance of rural life, nor do I believe it a mere chance that this development is so largely coincident with the development of agricultural science. While the beginnings of agricultural research in this country date back to the 50's, and while a notable increase of interest in it followed the establishment of the first agricultural experiment station in 1875, it was by the enactment of the Hatch Act, twenty years ago last March, that the United States definitely committed itself to the policy of promoting research in agriculture. The far-reaching effects of that act are becoming increasingly apparent, and by no means the least of these is the stimulus which it gave to agricultural education. The recent surprising growth of the agricultural colleges, and the still more recent development of secondary and primary agricultural education, all date substantially from 1887. Beginning with a keen appreciation of the material benefits accruing to technical agriculture from the investigations of the scientist, as demonstrated by the work of the experiment stations, this movement, while losing none of its practical character, is steadily broadening its scope. We are gradually coming to see that the function of science in relation to agriculture is not simply to perfect its technic and enhance its profits, but that its ultimate aim is nothing short of the uplifting of the whole body of the agricultural people. That this uplift began with the improvement of the physical conditions of farming is but a repetition of the experience of the ages. That it has so soon begun to take on the broader as-

pect is cause for profound satisfaction. Those who have aided, however humbly, in this advance may well feel that this fact is their chief reward, while the breadth and significance of this movement for the advancement of agriculture should appeal with tremendous force to the generous soul of youth. He who may reasonably hope to promote by his researches this vast movement need seek no further for a worthy career.

**End of
Title**